MASONRY DAMS

FROM

INCEPTION TO COMPLETION

C. F. COURTNEY, M. Inst. C. E.

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INCLUDING

NUMEROUS FORMULÆ, FORMS OF SPECIFICATION AND TENDER, POCKET DIAGRAM OF FORCES, ETC.

For the use of Civil and Mining Engineers

BY

C. F. COURTNEY, M.Inst.C.E.

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PREFACE.

The Author desires it to be understood that this little work does not pretend to furnish an exhaustive treatise on the Design and Construction of Masonry Dams, but merely to draw together briefly some necessary information, and to offer some assistance to the student in overcoming the many difficulties which are likely to present themselves in an undertaking of merit and importance.

The constant requirement of large bodies of water for mining works (works of that kind being now in active development and extension in all parts of the world—up-country mostly, oftentimes removed from opportunities of obtaining complete information as to water storage, &c., put together in a compact form) has induced the Author to write the following pages, in the hope that they may be of assistance particularly to those whose work is carried on away from the centres of practical information. Though presented by him with diffidence, it is hoped that the data herein

condensed may assist his fellow mining engineers in a few detailed difficulties and dangers.

The graphic system has been adopted in indicating the limits of pressure in the dam, being considered preferable to that of calculation. Any error in the use of simple graphic methods, instead of elaborate calculations, is at once proclaimed by the polygon of forces refusing to close; whereas a figure or a decimal point in calculations wrongly placed, but in every other way correct, may easily lead to extremely erroneous results, and possibly endanger the stability of the structure to which the problem relates. Full detailed calculations of stability are, however, given, as it may be desirable to employ both methods.

Carefully reading a book will not make an engineer; and it may be as well to remind those who are too apt to think otherwise that twenty or thirty years' experience cannot be obtained in that easy and rapid manner; and further, that although an effort is made in the following pages to clearly embrace the salient features in the construction of Masonry Dams from conception to finish, there is still left ample room for experience to affect the cost of construction. Moreover, to appreciate the delicacies of pressure, stability, and, above all, the dangers and risks of leakage, in such works, is vouchsafed only to those who have had long experience in engineering work.

Uniformity and completeness in a volume like the

present are only compatible with ample leisure, whilst the papers which form this little treatise were prepared during the spare evenings of active work.

It would be impossible to write such a book, or for the work to possess any practical value, without making frequent use of what has already been published; but where that has been done care has been taken, as far as possible, to acknowledge the source of information. Any omission in that respect is not due to intention.

C. F. COURTNEY.

NOTE.—In the absence abroad of Mr. C. F. COURTNEY, this volume has passed through the press without his personal supervision of the proof-sheets, and it has been a pleasure to me to undertake for him the friendly service of checking the proofs with his MSS.

HASTINGS C. DENT,
ASSOC.-MEMB. INST.C.E.

LONDON,
June, 1897.

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APPENDIX II.

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LIST OF ILLUSTRATIONS.

ERRATA.

Page 5, five lines from top, *read* "6·235 gallons," *in place of* "6,235."

Page 7, at bottom, the division of total ordinates *should be* "by 8," *not* "9," thus:—

$$\frac{0\ 1{\cdot}4\ 1{\cdot}6\ 2{\cdot}0\ 2{\cdot}1\ 1{\cdot}9\ 1{\cdot}8\ 1{\cdot}7\ 0}{8} = 1{\cdot}56$$

,, after square feet, *read* "$= 1{\cdot}56 \times 16 = 24{\cdot}96$," *in place of* "$1{\cdot}39 \times 16 = 22{\cdot}24$."

Page 8, nine lines from bottom, *read* "$24{\cdot}96 \times 4{\cdot}27$," *in place of* "$22{\cdot}24 \times 4{\cdot}27$." Next line *read* "106·58," *in place of* "94·96."

Page 12, three lines from top, *read* "walls," *instead of* "wells."

Page 17, "$b = \sqrt{H + 2}$ feet," *should be* "$b = \sqrt{H} + 2$ feet," and "$y = 0{\cdot}6x +$ as a minimum," *should be* "$y = 0{\cdot}6x$ as a minimum."

Page 18, two lines from bottom, *read* "closes," *in place of* "closer."

MASONRY DAMS.

SITE AND POSITION.

A subject of important consideration is the choice of situation, for, whether a dam be constructed for the retention of water for household consumption, irrigation, or manufacturing requirements, the site selected should be as free as possible from vegetation and great depth of soil, both being detrimental to cleanliness, purity of the water, and quantity given by the drainage area from the rainfall. A gradually rising area of great extent is preferable, so that the impounding space is large, with a dam of moderate height. Any area that has in past times become a lagoon or lake, and by the action of erosion cut an outlet forming a narrow neck for its discharge, is eminently suited, as invariably the upper and surrounding country is extensive, and insures an abundant supply of water from the rainfall. The sites are therefore restricted, and confined to such districts as are neither mountainous nor extremely flat, with sluggish watercourses. A position that commands an extensive drainage area, such as will yield more than the required quantity of water from the

average yearly rainfall without the necessity of extension by the employment of catch drains, becomes at once a most favourable site, as in no case will the water brought into requisition by catch drains supply the same available percentage of the rainfall as that derived from the catchment area appertaining to the reservoir. Should the area of the water retained in the reservoir by the dam be extensive, the evaporation will be considerable, and directly proportionate to the surface exposed to the sun's rays during dry seasons. The effects of evaporation must also be clearly borne in mind, as the total estimated to be retained for consumption will be seriously reduced. In humid climates, such as England, the evaporation is not excessive, ranging between five and ten per cent. of the total retained, whilst in the South of Spain and Egypt thirty-three per cent. is no unusual loss. From four to five feet depth of water from the surface of a reservoir is by no means an exceptional annual evaporation in those countries. It is therefore only possible in such regions, with light rainfall and great evaporation, to obtain an abundant supply by either diverting a river to the site of the reservoir or selecting an immense drainage area that conveniently converges towards the works.

For simplification of calculating the available water obtained from a given area the following might with advantage be committed to memory: Every centimetre of rainfall is equal to one cubic metre of water when falling upon one hundred square metres of ground: which, when multiplied by two hundred and twenty,

results in gallons. About fifty-five per cent. of this quantity will be found available when falling upon barren ground. Should, however, the annual rainfall be as low as twelve inches, and distributed over nine months of the year, the available quantity will not be more than twenty to twenty-five per cent.; if, on the other hand, between thirty and forty inches of rain fall during the same period, fifty to fifty-five per cent. will be obtained. Heavy storms will give as much as eighty to eighty-four per cent. of their water, there not being sufficient time for brushwood, heather, soil, or permeable detrimental strata to absorb the flood produced. Practically the whole of the water, therefore, runs rapidly into the watercourses.

Dew is also an element which affects an available supply, as in some countries it is very heavy, and if produced either from the moisture of the ground or condensed from the atmosphere it is still there, ready to assist the night or early morning rainfall to run freely into the valleys.

The evaporation from the sea on the shores of the Mediterranean is sufficient to yield about five times the quantity brought down by the watercourses. Messieurs Mariotte and Dausse ascertained that the annual quantity carried down by the Seine is not more than one-third of that supplied by the atmosphere to the country which it drains; the remaining two-thirds of the rain must, therefore, either be evaporated or absorbed by the vegetation. Carefully observing the foregoing features with study, and inquiring on the ground of an ultimately selected site, an estimate can

be made of the probable annual reliable supply that would be given by the drainage area.

Unfortunately many are unacquainted with the metric system. The following table will therefore assist in the computation of the cubic feet of water received per acre, &c., from various rainfalls :—

Rainfall in inches ...	1	2	3	4	5	6	7	8
Cubic feet per acre...	3,630	7,260	10,890	14,520	18,150	21,780	25,410	29,040
Million cubic feet per square mile	$2\frac{1}{3}$	$4\frac{1}{2}$	7	$9\frac{1}{4}$	$11\frac{1}{2}$	14	$16\frac{1}{4}$	$18\frac{1}{2}$

Rainfall in inches ...	9	10	12	15	20	25	30
Cubic feet per acre...	32,670	36,300	43,560	54,450	72,600	90,750	108,900
Million cubic feet per square mile	21	$23\frac{1}{4}$	$27\frac{3}{4}$	$34\frac{3}{4}$	$46\frac{1}{2}$	58	$69\frac{3}{4}$

Rainfall in inches ...	40	50	60	70	80	90	100
Cubic feet per acre...	145,200	181,500	217,800	254,100	290,400	326,700	363,000
Million cubic feet per square mile	93	$116\frac{1}{4}$	$139\frac{1}{2}$	$162\frac{1}{2}$	$185\frac{3}{4}$	209	$232\frac{1}{4}$

The undermentioned multipliers will also be found serviceable :—Inches of rainfall $\times$ 2,323,200 = cubic feet per sq. mile. Inches of rainfall $\times$ $14\frac{1}{2}$ = millions of gallons per sq. mile. Inches of rainfall $\times$ 3,630 = cubic feet per acre. One cubic foot $\times$ 6,235 = gallons. One cubic metre $\times$ 220 = gallons.

As the general health of a district may be seriously affected by the proximity of a large area of water in warm or semi-tropical climates, it is necessary to remark that all stagnant water is productive of malaria; the sudden change of temperature in hot climates at sundown or sunrise causes a sickening and chilling miasma to rise from all low-lying ground, which is greatly intensified where water is retained. That which was intended, therefore, for the benefit of a district may become of doubtful advantage to the immediate neighbourhood, a persistent and insidious fever being the result of what is otherwise a magnificent and beneficent water supply.

GAUGING A PROPOSED SOURCE OF SUPPLY.

In utilising a river as a permanent supply, calculations require to be made at various times in the year of its discharge before any definite opinion can be formed as to its minimum supply, and for this purpose a weir or notch board is the simplest and most convenient. This is very easily erected at small cost, consisting of a small dam, made by fixing planks across the river, and a notch cut upon the upper plank; a sill, over which the whole of the water of the stream or river is made to run, being formed by cutting a feather edge on the wood, or by fixing a thin brass plate. The opening must have perfectly vertical sides, and the sill be horizontal; the water approaching the weir should not have an appreciable velocity, or the calculation is more troublesome.

The formula that can be applied for the calculation of the discharge of water over the temporary weir is due to Mr. J. B. Wood, C.E., and is sufficiently accurate without being complicated:—

$$Q = 3{\cdot}33\ (l - 0{\cdot}2\ H)\ H^{\frac{3}{2}}.$$

Q = Quantity of water in cubic feet per second.

l = Length of weir in feet.

H = Depth of water in feet passing over the weir—

that is to say, the difference of level between the sill of the weir and the water in the pool behind the weir.

In cases where the water approaches the weir at an appreciable velocity the following corrected formula is used:—

$$Q = 3{\cdot}33\ (l - 0{\cdot}2\ H_1)\ H_1^{\frac{3}{2}};$$

in which $H_1 = H + h$,

h being $\dfrac{v^2}{64{\cdot}4}$

v = the velocity of the approaching water in feet per second.

Should, however, the discharge of a river or stream be so large that a temporary dam with notch board becomes impracticable, another method must be employed which will give rough but fairly reliable data.

A site is selected where there is a somewhat even and regular flow of the water, and three or four careful cross-sections are taken, being marked off on the bank at equal distance the one from the other. Each section would give a figure somewhat like the following, and

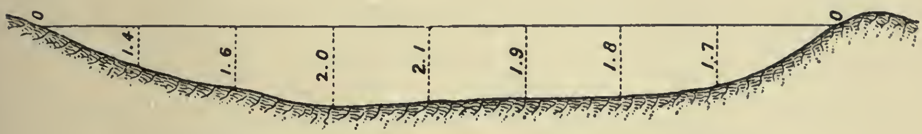


FIG. A.

the average depth would therefore be

$$\frac{0 + 1{\cdot}4 + 1{\cdot}6 + 2{\cdot}0 + 2{\cdot}1 + 1{\cdot}9 + 1{\cdot}8 + 1{\cdot}7 + 0}{9} = 1{\cdot}39$$

Should the width be sixteen feet, the section in square feet $= 1{\cdot}39 \times 16 = 22{\cdot}24$.

The average of the three or four sections taken will therefore be the average square feet of water moving between the sections.

What is now required to ascertain the discharge of the river is the velocity of the water; to obtain this, a well arranged float that can be distinctly seen, and at least three-fourths submerged, is placed in the centre of the river some little distance above the line of the first section. On noting the time of passing the first and last sections we might have, knowing the exact distances travelled, a surface velocity, for instance, of 5·7 feet per second. A number of observations are taken, and the mean of them is the surface velocity.

The mean velocity of a river, however, is less than the surface velocity, and for rough estimations may be taken as three-fourths of the mean of the observed velocities; we should have, therefore, $5{\cdot}7 \times \frac{3}{4} = 4{\cdot}27$ feet per second. $22{\cdot}24 \times 4{\cdot}27$ is consequently the discharge, which in this case equals 94·96 cubic feet per second.

This may be taken as the minimum discharge, as four-fifths of the surface velocity is a nearer approximation to take for the mean velocity of a stream.

The following table may be considered as giving the maximum mean velocity, corresponding to the surface velocity :—

TABLE OF VELOCITIES OF STREAMS.

Surface Velocity.	Mean Velocity.	Surface Velocity.	Mean Velocity.	Surface Velocity.	Mean Velocity.
120	98·00	212·5	182·40	310	273·1
122·5	100·25	215	184·75	315	277·8
125	102·50	217·5	187·05	320	282·5
127·5	104·75	220	189·35	325	287·2
130	107·00	222·5	191·65	330	291·9
132·5	109·25	225	193·95	335	296·6
135	111·55	227·5	196·30	340	301·2
137·5	113·80	230	198·60	345	305·9
140	116·05	232·5	200·90	350	310·6
142·5	118·30	235	203·25	355	315·3
145	120·60	237·5	205·55	360	320·1
147·5	122·85	240	207·85	365	324·8
150	125·15	242·5	210·20	370	329·5
152·5	127·40	245	212·50	375	334·2
155	129·65	247·5	214·85	380	338·9
157·5	131·95	250	217·15	385	343·6
160	134·20	252·5	219·50	390	348·3
162·5	136·50	255	221·80	395	353·0
165	138·80	257·5	224·15	400	357·8
167·5	141·05	260	226·45	405	362·5
170	143·35	262·5	228·80	410	367·2
172·5	145·65	265	231·10	415	371·9
175	147·95	267·5	233·45	420	376·7
177·5	150·20	270	235·75	425	381·4
180	152·50	272·5	238·10	430	386·1
182·5	154·80	275	240·45	435	390·8.
185	157·10	277·5	242·75	440	395·6
187·5	159·40	280	245·10	445	400·3
190	161·70	282·5	247·45	450	405·1
192·5	164·00	285	249·75	500	452·5
195	166·30	287·5	252·10	550	500·0
197·5	168·60	290	254·45	600	547·7
200	170·90	292·5	256·75	650	595·5
202·5	173·20	295	259·10	700	643·3
205	175·50	297·5	261·45	750	691·2
207·5	177·80	300	263·75	800	739·2
210	180·10	305	268·40		

LOCATION OF DAM.

Having settled upon a site that meets in every respect the requirements demanded—which embraces extensively the utilization of every source of supply, and the adaptation of such sources to the required object under investigation—the next point to be studied is the one of locating the precise position where the dam is to be built; and herein are involved a few matters that call for special consideration. It is of course understood that an impounding reservoir cannot be constructed unless there be an impervious bed under it at such a depth as to permit the construction of the dam being practicable. It is often found that where two streams meet a contraction of the valley occurs a little lower down, and the best site for the erection of a dam is where a valley widens out into a flat area bounded by steep sides, there generally being a contraction of the valley in close proximity.

The quality, condition, and class of rock; inclination of strata, permeability, and direction; whether in closing the valley the strata will pass obliquely under the dam at right angles or parallel with it—are all matters requiring consideration. Observation will also be made as to whether any portion of the district has been recently or in past times subjected to the dis-

turbing influence of volcanic eruption or earthquake shocks. The solidity of the rock upon which the dam is to be founded is also of great importance, whilst faults or small fissures filled with clay will inevitably lead to an immense amount of excavation. It is usual, therefore, to test the ground by bores, or, preferably, shafts sunk along the line where the proposed dam is to be built. In this way the condition of the rock, the depth of the loose subsoil, and the importance of discovering any springs of water, which cause great trouble and danger in the foundations, will be at once ascertained. Too little attention is often paid to these details, with the result that as much masonry has to be placed below the surface of the ground as there is in the superstructure, with a corresponding enormous increase upon the original estimate of the work. The author has known a case where, the test shafts not being sunk deep enough, the result was that the estimated cost of the works was exceeded by twenty-three per cent.

The fall of the watercourse in which the dam is to be erected has a direct relationship to its height, a rapid course requiring a greater height of dam to give a large impounding space.

Having located the ultimate position of the dam, we can next proceed, by the aid of carefully surveyed contour lines, which have been previously set out on the ground at every three or four feet height, to calculate at various heights the capacity obtained, the required capacity indicating the necessary height of the dam.

At a point near where the various watercourses upon which we depend for supply touch the water when the reservoir is full, wells should be built of dry stone or otherwise for the purpose of retaining the silt which will be brought down by heavy rainfalls. In this way a great quantity of detritus will be checked from being swept into and depositing on the bottom of the reservoir, and so reducing its capacity. Each silt deposit can be conveniently cleaned when full, probably during dry weather, at small expense. As the bulk of the silt will be brought down during heavy storms, allowance may be made for passing off the water by a by-wash when the reservoir is full; this also relieves any undue strain upon the wall from a sudden rise of the surface of the water, and further insures that the overflow provided is under all circumstances ample.

All vegetation within the reservoir area should be collected, removed, or burnt, as the water is liable to suffer for a few years from the decaying vegetable matter. The whole catchment area must in fact be very carefully preserved, and no farming operations permitted within it, or otherwise at certain seasons of the year impurities will be found in the water which may render it dangerous for drinking purposes. A variation in the purity of the water from the famous Loch Katrine being observed, it was found on investigation to be caused by a farmer within the catchment area having, just before a very heavy fall of rain, used manure for his ground somewhat extensively.

CALCULATIONS OF STABILITY.

For a masonry dam to be perfectly stable the following conditions must be complied with :—

1. No part of the masonry must be in tension.
2. No part of the structure must be under more than a certain pressure from the superincumbent weight.
3. It must by friction alone resist any tendency to slide on its base.
4. It must by its own weight alone be able to resist all tendency to overturn by water pressure or the pressure of uneven winds, &c.
5. There must be such a width given to the top as to counteract the effects of expansion and contraction.

Professor Rankine points out that, theoretically, if the limits of pressure fall outside the centre third of the profile the structure is exposed to tension. The line of pressure—called also by some engineers the line of resistance—should therefore fall within the centre third, for if the requirement as to tension be fulfilled we have Conditions 2 to 4 complied with. The line of pressure is a line intersecting each joint of a structure at the point of application of the resultant of all the forces acting on that joint.

To calculate the best section that fulfils the above requirements, without any practical important excess in expenditure of material beyond what is necessary, is a very complicated problem, but with care and trouble it can be greatly simplified. The system that has been generally adopted is to make a number of trial profiles, and to adopt the one that gives the required lines. Mr. W. B. Coventry remarks, in his memoir on the "Design and Stability of Masonry Dams:"—"Owing to the indeterminate nature of the problem, it seems impossible to construct a general formula for calculating the dimensions of a dam, and the method usually followed consists in assuming an approximate profile, and then testing its stability by a graphic resolution of forces. If found defective, the profile is altered, and the graphic process repeated until a sufficiently exact result is obtained."

A correct profile may undoubtedly be found by making a number of trials, but it is extremely laborious, and may involve several days, and perhaps weeks, of unsatisfactory work, although it may be impossible to determine at once the proper section of minimum area which incorporates the required conditions; yet an approximate profile may be obtained by the application of a very simple formula giving polygonal outlines of inelegant form, and in every respect sufficiently accurate and practical to bear upon it the ultimate design. Very little attention is generally paid to the appearance of a dam, its calculated form being considered sufficient; with the result that a large expenditure may produce a structure of ungainly form, fulfilling the purpose for

which it was intended, no doubt, but doing little credit to the engineer as designer. There is less intelligence required to develop on paper a structure that adheres to theoretical requirements, but the combination of security and beauty of form generally involves a higher capacity; hence our feelings are continually being outraged by the ineffective and inelegant structures around us.

The ultimate profile should adhere undoubtedly to the required theoretical profile, but there are a few things that the formula does not and cannot take into account—which, when allowed for, can be incorporated in the design of outline.

The top width of a dam is a matter of judgment, and it is this width, which cannot be calculated theoretically, that will assist the designer, if taken advantage of, to produce a pleasing and graceful form. Condition No. 5 is of great importance, and involves the following points.

Expansion and contraction are proportionate to the length, the width increasing or checking that effect according as it is wide or narrow.

The top, if vertical for eight to ten feet at the back, causes it to appear when built as if leaning over, thereby destroying when executed what may be a very pleasing effect in the original drawings.

The great heat of tropical and semi-tropical climes during the day has a very decided expanding influence upon the masonry, the author being acquainted with one masonry dam that is cracked in two places from the top downwards for a depth of eight to twelve feet,

and passes a stream of water during the winter, while in the summer months it is perfectly water-tight; the top width, however, is only six feet six inches, instead of being eight feet three inches, in which case these cracks would not have taken place.

High masonry dams are usually required to close deep gorges and valleys, having consequently less length of top to depth than low masonry dams, which may impound the same quantity of water, but, being in flat and low-lying country, will be of excessive length to depth; by taking $\sqrt{H}+2$ feet (where H equals height) for width of top, a wide top in proportion to height is obtained for low dams and a gradually decreasing width to height in high dams.

It is necessary, then, that a theoretical profile should embrace and allow for the above in all cases, which the following very simple formula does; and, that the width at quarter height from the top shall be dependent upon beauty of outline rather than strict mathematical rule. By a slight modification of Sir Guilford Molesworth's formula we have one which is applicable to both high and low dams; whilst the method employed in obtaining the offset to the inner face is very simple, and results in a very close approximation to Rankine's theoretical profile, as well as the practical or ultimate profile obtained for the inner face of the Quaker Bridge Dam, built for the supply of water for New York, which has a maximum height of upwards of 250 feet (see Fig. D, *post*, p. 41).

The following formula, therefore, may be adopted

in ascertaining any theoretical profile, and will meet rigidly the requirements of stability, which can be afterwards ascertained by the graphic system, and by calculation as a check if desired :—

$$b = \sqrt{H + 2}\ \text{feet}$$

$$a = \frac{H}{4} \times 0{\cdot}72$$

$$y = \sqrt{\left(\frac{0{\cdot}05x^3}{\lambda + (0{\cdot}03x)}\right)}$$

$y = 0{\cdot}6x +$ as a minimum

$z = \dfrac{f}{25}$ for 100 feet depth,

or $\left(\dfrac{0{\cdot}09x}{\lambda}\right)^3$ approximately for all depths.

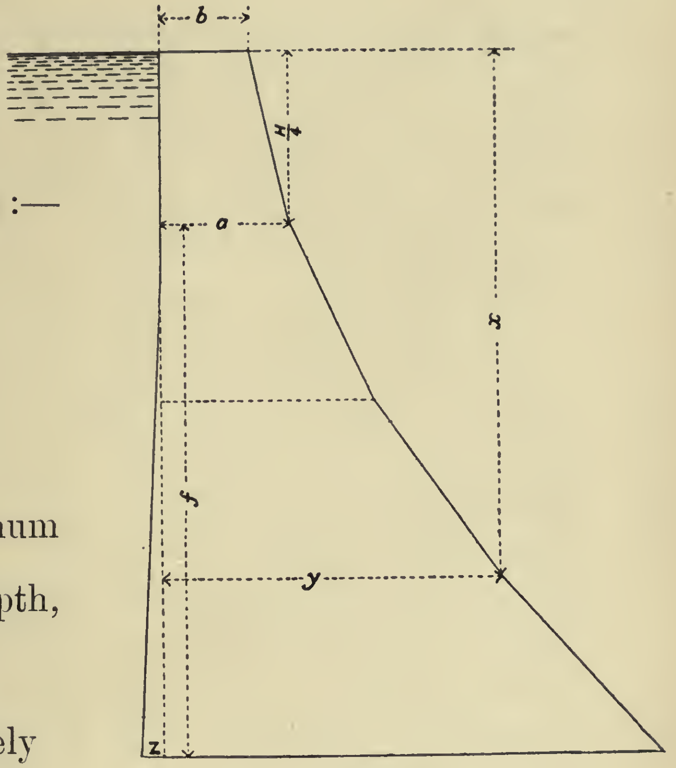


Fig. B.

Where (Fig. B) H = Total height of dam in feet.

λ = A constant of seven to be used for all depths.

x = Depth below the surface of water in feet.

y = Offset in feet to the outer face of the dam from a vertical line corresponding to the inner face at the top.

z = Offset to the inner face from the same vertical line.

The above formula will give for a dam of 100 feet in height the outline shown on the diagram of forces

accompanying this work,* the dotted lines giving Molesworth's outline, the width of the top of the dam b being $0{\cdot}4y$ at $\frac{1}{4}$ H and the offset $z = \left(\frac{0{\cdot}09x}{\lambda}\right)^4$, λ being limit of pressure allowed on the masonry in tons per square foot, which is taken as seven in this case. The symbol λ, being equal to the limit of pressure allowed on the masonry, can be varied; any less pressure, such as five or six tons, being adopted, gives a greater width to the dam; above seven a decreased width. These ciphers are, however, empirical, and have no relation to the pressure per square foot obtained by the combined water and masonry upon the outer portion of the dam. A constant of seven has therefore been adopted in the place of any varying limit of pressure per square foot.

Having by this simple method drawn out our theoretical profile by dividing it into four sections, we can proceed to design upon this outline the ultimate form which the wall shall assume, being guided by the width at $\frac{H}{4}$, this width being, by the method adopted, obtained, and dependent upon an outline that combines rigidity (at the very point that is most exposed to expansion and contraction from the sun's rays) and elegance of form. This is very simply obtained by applying a curve that will start tangentially with any point at the outer face at about half the total height of the dam, passing through the point given for the quarter height and meeting the top edge; from the half height to the base another curve will be drawn in that, closer, with the calculated widths at the half height, three-quarter height,

* For diagram, see loose sheet in pocket of cover of this book.

and the base. These two curves, it will be noticed, encroach somewhat upon the trapezium given by the formula on each section; but if the total height be divided into more than four planes the curved lines will approximate more closely to the polygonal lines of the outer face. We have, therefore, after completing this operation, an ultimate or practical profile, upon which may be based the diagram of forces, in order to ascertain the lines of resistance, with reservoir full and empty.

In order to proceed, it is necessary to settle what weight per cubic foot of masonry is to be adopted, as the calculation will be based upon a section of the dam the length of which is unity, or, in other words, a section the thickness of which is one foot. The proportions of stone to mortar in a well built dam will be two-thirds stone and one-third mortar; the stone employed should not have a less specific gravity than 2·5; the cubic metre will therefore weigh 2,500 kilogrammes. A cement mortar composed of one to three of sand—the sand being washed after passing through a one-eighth inch square hole sieve, and the weight of the cement being equal to ninety pounds per striked cubic foot—will have a specific gravity of 2·02 when fresh, but the immediate evaporation which is produced by chemical combination, and the drying which takes place afterwards, result in giving 1·99.

The density of the masonry can therefore be ascertained as follows:—

	Kilos. per c. metre.	Lbs. per c. foot.
$\frac{2}{3}$ of stone at 2,500 kilogrammes per cubic metre =	1,666	104·04
$\frac{1}{3}$ of mortar at 1,990 kilogrammes per cubic metre =	663	41·40
Total weight	2,329	145·44

The density can therefore be taken at 145lbs. per cubic foot, which will ensure, if adhered to in construction, a perfectly sound monolith; with a specially sound and heavy stone, and increasing the proportion of cement, the density would rise to 150lbs. per cubic foot, or even 155lbs. For high masonry dams of over 100 feet no more material should be used than will result in a less density than 145lbs. per cubic foot; for dams of fifty feet and less a poorer class of stone may be employed, and the masonry might have a density of not more than 130lbs. per cubic foot and be perfectly safe.

The higher the density adopted the safer the work will be, as it necessitates good material.

The next point of importance that requires consideration is the limit of pressure on the masonry at the base of the wall. It must be noticed that in buildings of this kind the mortar plays a considerable part, and on its resistance the work depends. The crushing force on an eminently hydraulic mortar composed of one of cement to three of sand, when placed under the condition in which it is found in masonry—being confined, that is to say, and subjected to lateral pressure—will be not less than 130 tons per square foot after aging. Taking one-tenth of the crushing force as the limit of pressure, we have thirteen tons per square foot. By adhering to the rule that the lines of resistance shall fall within the middle third, with the density of the masonry taken as 150lbs. per cubic foot, the pressure on the outer base of the wall will not be more than 6·35 tons per square foot at 100 feet depth, 8·11 tons at 150 feet, and 10·47 tons at

200 feet. There is no chance, therefore, of the combined masonry and water pressures exceeding this limit, whilst for dams of 200 feet depth a stronger mortar would probably be used than one to three, and thereby resist a greater crushing force.

Having determined the density, and ascertained the limit of pressure to be applied at the base, and drawn out the profile according to the amended formula, the next step is to calculate the areas, weight, and centre of gravity of the four sections into which the profile is divided, and ascertain the direction and intensity of the resultant on each plane respectively.

The determinations of the centres of gravity and pressures, &c., are adopted with modifications from the method employed by Sir Guilford Molesworth in his notes on "High Masonry Dams," the whole of which can be readily understood by the aid of the diagram appended.

To determine the centre of gravity of the masonry in each section separately:—

Let A, B, C, D (Fig. 2, Diagram) be any section (in this case the section overlaying the plane d, Fig. 1, Diagram).

Draw the diagonals $A\,D$, $C\,B$; S being the point of their intersection. Make $D\,E = A\,S$, join $E\,C$, and bisect the lines $C\,B$ and $E\,C$ at F and H respectively; join $F\,E$ and $H\,B$; then the intersection of the lines $F\,E$ and $H\,B$ at G gives the position of the centre of gravity of the masonry above (marked also by small circles at end of arrow in each section, Fig. 1, Diagram).

To determine the position of the centre of gravity of the

masonry and of the vertical pressure of the water for each section separately :—

In any convenient position make a diagram for the polygon of forces (Fig. 3, Diagram) as follows :—

On a vertical line lay off with any convenient scale; JK = the vertical water pressure on the face AC, and with the same scale lay off KL = weight of the masonry in the section A, B, C, D. Take any convenient point M (the position of M is immaterial); join LM, KM, and JM; then these lines give the direction of the lines for the polygon of forces (Fig. 4), which is formed as follows :—

Bisect AC in T and draw vertical lines through T and G. Then from any convenient point, N, in the vertical line which passes through T draw the line NR parallel to MK; then from N and R draw the lines NQ and RQ parallel to MJ and ML respectively. The point Q at the intersection of the lines NQ and RQ gives the position of a vertical line which will pass through the mean centre of gravity of the masonry and water pressure.

To determine the centre of gravity of the total pressure overlaying each plane :—

(a) Reservoir full.—The centre of gravity of each section having been found, as described above, form a diagram for the polygon of forces as before, laying off $ef = Pa$; $eg = (P + \Pi v)\, b$; $eh = (P + \Pi v)\, c$; $ej = (P + \Pi v)\, d$ (see Fig. 5, Diagram). Take any convenient point k, and join ek, fk, gk, hk, and jk. Then form a polygon of forces (see Fig. 6, Diagram) as follows :—

From any convenient point l in the vertical line that passes through the centre of gravity of the weights of masonry overlaying the plane a, draw $l\,q$ parallel to $e\,k$, $l\,m$ parallel to $k\,f$ until it intersects at m the vertical line which passes through the centre of gravity of the weight of masonry and vertical water pressure of that section contained between the planes a and b; then through m draw $m\,n$ parallel to $k\,g$ until it intersects at n the vertical line which passes through the centre of gravity of the weight of masonry and vertical water pressure of that section of the dam that lies between the planes b and c; then through n draw $n\,p$ parallel to $k\,h$ until it intersects at p the vertical line which passes through the centre of gravity of the weight of masonry and of vertical water pressure of the section that lies between the planes c and d, and from p draw a line parallel to $k\,j$ until it intersects the line $l\,q$. Then the points of intersection of these lines at s, r, and q give the position of vertical lines which will pass through the centre of gravity of the loads overlaying the planes b, c, and d respectively, the centre of gravity of the weight overlaying the plane a having previously been determined.

(*b*) Reservoir empty.—The centres of gravity for the empty reservoir are found in the same manner as above, laying off in the diagram for the polygon of forces P in every case instead of $P + \Pi v$. The diagram and the polygon of forces in the case of an empty reservoir are shown in dotted lines when they differ from those of the full reservoir.

To determine the resultants of pressure for each plane, the reservoir being full :—

Find the centre of horizontal pressure of water for each plane, equal two-thirds of the depth of the plane below the surface of the water; then from each point in the polygon of forces l, s, r, and q draw vertical lines to the intersection of the horizontal line of the centres of pressure respectively (these intersections are shown by the centres of circles in Fig. 1, Diagram); then from these points of intersection lay off with any convenient scale a vertical distance $= P + \Pi v$, and from the vertical distance so laid off lay off a horizontal distance $= \Pi h$; then a line from the intersection of the centres of gravity and horizontal pressure of water to the point given by this horizontal distance will represent the direction of the resultant of the weight of the masonry and of the water pressure, and where this line intersects the plane will be the centre of pressure of the resultant on the plane in question.

To determine the centre of pressure for each plane, the reservoir being empty :—

Vertical lines drawn from points v, w, y, l in the polygon of forces for the empty reservoir to the planes d, c, b, and a respectively give points in those planes for the centre of pressure.

It is obvious that the centre of gravity obtained by the above method is applicable only when each section is of trapezoidal form, as in the case of the four sections in the Diagram, Fig. 1, which is perfectly accurate for all practical purposes; should, however, it be thought

desirable to adhere strictly to the final form—that is to say, the curved form on the down stream face—the following simple method may be adopted: Transfer the final and adopted profile to a piece of pasteboard, which must be carefully cut to the outline, suspend it from one of the corners of its base; and drop a vertical from the point of suspension, which line must be marked upon the profile, and a similar operation performed from the opposite side of the base; the point where these two vertical lines intersect is the grand centre of gravity of the masonry. To obtain the same for each section the pasteboard profile must be cut along the lines of the four planes of the sections into which the whole is divided, and by so doing separate the one from the other; repeat the same operations on each section separately, as was done for the whole profile; this will give the centre of gravity of each section.

For the purpose of checking the lines obtained by the application of the graphic system, it might be found convenient and satisfactory to derive the same result mathematically. The whole of the calculations necessary are therefore given in the following pages, and will explain themselves.

The profile, as before, is divided into four sections, and the following description corresponds to the symbols used:—

H = Height of dam.

λ = A constant of 7.

l = The length of the horizontal plane or joint in question.

P = The resultant of the weight of the overlying masonry.

Πv = The vertical component of the pressure of the overlying water.

Πh = The horizontal component of the same.

x = Depth of the imaginary horizontal plane below the surface of the water.

y = The ordinate from the vertical line to the down stream face (y_1 and y_2 being the down stream ordinates on the top and bottom of any section respectively).

z = The ordinate to the up stream face (z_1 and z_2 being the up stream ordinates on the top and bottom of any section respectively).

w = Vertical component of water pressure on each section of the dam.

W = Vertical component of pressure of masonry for each section of the dam.

g = The distance of the centre of gravity of all the masonry overlying any plane measured from the vertical line towards the down stream face, the reservoir being empty.

g^1 = The distance of the centre of gravity of all the masonry and the whole of the vertical component of water pressure overlying any plane measured from the vertical line towards the down stream face, reservoir full.

g_y = Distance of the centre of gravity of that portion of each section which lies down stream of the vertical line, measured from that line towards the down stream face.

g_z = Distance of the centre of gravity of the up stream portion of each section, measured in the up stream direction.

gm = Distance of the centre of gravity of the whole of the masonry in each section measured from the vertical line towards the down stream face.

gmw = Distance of the mean centre of gravity of the masonry and of the vertical water pressure of each section measured from the vertical line towards the down stream face.

m = Moments of each section; or weight due to each section separately multiplied by gm or gmw respectively for empty or full reservoir.

M = Sum of the total moments overlaying each plane, reservoir empty.

M^1 = Sum of the total moments overlaying each plane, reservoir full.

c = Depth of the centre of the horizontal pressure of the water below its surface.

u = The distance of the up stream face measured on an imaginary horizontal plane from the foot of the resultant of the weight of the overlaying masonry, the reservoir being empty.

u^1 = The distance of the down stream face measured on an imaginary horizontal plane from the foot of the resultant of the pressure of the water and of the weight of the overlaying masonry.

p = Resultant pressures of masonry and water on bearing surface of each plane; the bearing surface being from a vertical line passing through the centre of gravity of the weight of masonry and vertical water pressure of each section to down stream face.

DETAILED CALCULATION OF MASONRY DAM OF 100 FEET HEIGHT.

DENSITY OF MASONRY 145 LBS. PER CUBIC FOOT = (0·06473 TONS PER C. FT.).

No.	Description.	Symbol.	Imaginary Planes.				Notes.
			a.	*b.*	*c.*	*d.*	
[1]	$x=$	x	25	50	75	100	Feet.
	$y=\sqrt{\left(\frac{0{\cdot}05\,x^3}{\lambda+(0{\cdot}03\,x)}\right)}=$		10·04	27·12	47·75	70·71	,,
	$y=$as a minimum $0{\cdot}6\,x$		15	30	45	60	,,
	Width at top $=\sqrt{H}+2=12$	b					
	$y=$at $\frac{1}{4}$ $H=\frac{H}{4}\times 0{\cdot}72=$	a	18				,,
[2]	y as adopted = ...	y	18	30	47·75	70·71	,,
[3]	$z=$Batter of 1 in 25 from $\frac{H}{4}$ downwards = ...	z	0	1	2	3	,,
[4]	Length of point $=y+z=$	l	18	31	49·75	73·71	,,
[5]	Mean width of each section = ...		15	24·5	40·375	61·73	,,
[6]	Area of each section $=[5]\times h=$		375	612·5	1,009·375	1,543·25	Square feet, $h=25$ ft.
[7]	Weight of each section 1 ft. wide = [6] × 0·06473 tons = ...	W	24·274	39·647	65·337	99·895	Tons.
[8]	Weight of masonry above each plane = ...	P	24·274	63·921	129·258	229·153	,,
[9]	Vertical pressure of water on each section = $z_2-z_1\left\{x_2-\frac{x_2-x_1}{2}\right\}\times 0{\cdot}02787$ tons = ...	w	0				Weight of 1 c. ft. of water = 0·02787 tons.
	$1-0\left\{50-\frac{50-25}{2}\right\}\times 0{\cdot}02787$,, = ...	,,		1·05			Tons.
	$2-1\left\{75-\frac{75-50}{2}\right\}\times 0{\cdot}02787$,, = ...	,,			1·74		,,
	$3-2\left\{100-\frac{160-75}{2}\right\}\times 0{\cdot}02787$,, = ...	,,				2·44	,,

[10]	Vertical component of water pressure on each plane = ...	Πv	0	1·05	2·79	5·23	,,
[11]	Vertical press of masonry and water on each plane [8] + [10] = ...	$P+\Pi v$	24·274	64·97	132·05	234·38	,,
[12]	Horizontal water pressure $= 0·013934\, x^2 =$	Πh					,, 0·013934 = weight of 1 c. ft. of water in tons divided by 2.
	$0·013934 \times 25^2 =$	,,	8·71				Tons.
	$0·013934 \times 50^2 =$	,,		34·84			,,
	$0.013934 \times 75^2 =$	,,			78·38		,,
	$0·013934 \times 100^2 =$	,,				139·34	,,
	Depth of centre of pressure $= \frac{2}{3} x =$	c	16·67	33·33	50	66·67	Feet.
[13]	Coefficient of sliding forces $= \frac{[12]}{[11]} =$	$\frac{\Pi h}{P+\Pi v}$					Limit = 0·76, which is the tangent of the angle of repose of masonry.
	$\frac{8·71}{24·27} =$		0·359				
	$\frac{34·84}{64·97} =$			0·536			
	$\frac{78·38}{132·05} =$				0·594		
	$\frac{139·34}{234·38} =$ ...					0·595	
	Details of the determination of the Centres of Gravity, &c., by calculation.						
	$\frac{1}{3}\left(y_1+y_2-\frac{y_1\, y_2}{y_1+y_2}\right) =$	g_y					
	$\frac{1}{3}\left(12+18-\frac{12\times 18}{12+18}\right) =$	,,	7·60				Feet.
	$\frac{1}{3}\left(18+30-\frac{18\times 30}{18+30}\right) =$	,,		12·25			,,
	$\frac{1}{3}\left(30+47·75-\frac{30\times 47·75}{30+47·75}\right) =$	,,			19·78		,,
	$\frac{1}{3}\left(47·75+70·71-\frac{47·75\times 70·71}{47·75+70·71}\right) =$					29·99	,,

DETAILED CALCULATION OF MASONRY DAM OF 100 FEET HEIGHT—(*continued*).

No.	Description.	Symbol.	Imaginary Planes.				Notes.
			a.	*b.*	*c.*	*d.*	
	$\frac{1}{3}\left(z_1+z_2-\frac{z_1\ z_2}{z_1+z_2}\right)$ = ...	g_z	0				Feet vertical face.
	$\frac{1}{3}\left(0+1-\frac{0\times 1}{0+1}\right)$ = ...	,,		0·33			,,
	$\frac{1}{3}\left(1+2-\frac{1\times 2}{1+2}\right)$ = ...	,,			0·78		,,
	$\frac{1}{3}\left(2+3-\frac{2\times 3}{2+3}\right)$ = ...	,,				1·27	,,
	$gy-\frac{z_1+z_2\ (gy+gz)}{z_1+z_2+y_1+y_2}$ = ...	gm	7·60				,, vertical face.
	$12{\cdot}25-\frac{0+1\ (12{\cdot}25+0{\cdot}33)}{0+1+18+30}$ = ...			11·99			,,
	$19{\cdot}78-\frac{1+2\ (19{\cdot}78+0{\cdot}78)}{1+2+30+47{\cdot}75}$ = ...				19·02		,,
	$29{\cdot}99-\frac{2+3\ (29{\cdot}99+1{\cdot}27)}{2+3+47{\cdot}75+70{\cdot}71}$ = ...					28·72	,,
	$\frac{gm-w\ (z_2-\frac{z_2-z_1}{2}+gm)}{W+w}$ = ...	gmw	7·60				,, vertical face.
	$11{\cdot}99-\frac{1{\cdot}05\ (1-\frac{1-0}{2}+11{\cdot}99)}{39{\cdot}65+1{\cdot}05}$ = ...			11·67			,,
	$19{\cdot}02-\frac{1{\cdot}74\ (2-\frac{2-1}{2}+19{\cdot}02)}{65{\cdot}34+1{\cdot}74}$ = ...				18·49		,,
	$28{\cdot}72-\frac{2{\cdot}44\ (3-\frac{3-2}{2}+28{\cdot}72)}{99{\cdot}90+2{\cdot}44}$ = ...					27·98	,,

	$W \times gm$ = ...	m					
	$24{\cdot}27 \times 7{\cdot}60$ = ...		184·45				
	$39{\cdot}65 \times 11{\cdot}99$ = ...			475·40			Reservoir empty.
	$65{\cdot}34 \times 19{\cdot}02$ = ...				1242·77		
	$99{\cdot}90 \times 28{\cdot}72$ = ...					2869·13	
	Reservoir empty $= \Sigma m =$	M	184·45	659·85	1902·62	4771·75	Sum of moments.
	$(W+w)\, gmw$ = ...	m^1					
	$(24{\cdot}27+0)\ 7{\cdot}60$ = ...		184·45				
	$(39{\cdot}65+1{\cdot}05)\ 11{\cdot}67$ = ...			474·97			Reservoir full.
	$(65{\cdot}34+1{\cdot}74)\ 18{\cdot}49$ = ...				1240·31		
	$(99{\cdot}90+2{\cdot}44)\ 27{\cdot}98$ = ...					2863·47	
	Reservoir full $= \Sigma m^1 =$	M^1	184·45	659·42	1899·73	4763·20	Sum of moments.
[14]	$\frac{M}{P}$ = Reservoir empty = ...	g					Feet.
	$\frac{184{\cdot}45}{24{\cdot}27}$ = ...		7·60				,,
	$\frac{659{\cdot}85}{63{\cdot}92}$ = ...			10·32			,,
	$\frac{1902{\cdot}62}{129{\cdot}26}$ = ...				14·72		,,
	$\frac{4771{\cdot}75}{229{\cdot}15}$ =					20·82	,,
[15]	$\frac{M^1}{P+\Pi v}$ = Reservoir full = ...	g^1					,,
	$\frac{184{\cdot}45}{24{\cdot}27}$ = ...		7·60				,,
	$\frac{659{\cdot}42}{64{\cdot}97}$ = ...			10·15			,,
	$\frac{1899{\cdot}73}{132{\cdot}05}$ = ...				14·39		,,
	$\frac{4763{\cdot}20}{234{\cdot}38}$ =					20·32	,,

DETAILED CALCULATION OF MASONRY DAM OF 100 FEET HEIGHT—(*continued*).

No.	Description.	Symbol.	Imaginary Planes.				Notes.
			a.	b.	c.	d.	
[16]	$z+g=$	u	7·60	11·32	16·72	23·82	Feet. Reservoir empty.
[17]	$y-\left\{g^1+(x-c)\dfrac{\Pi h}{P+\Pi v}\right\}=$	u^1					
	$18-\{7·60+(25-16·67)\ 0·359\}=$		7·41				,, Reservoir full.
	$30-\{10·15+(50-33·33)\ 0·536\}=$			10·91			,,
	$47·75-\{14·39+(75-50)\ 0·594\}=$				18·51		,,
	$70·71-\{20·32+(100-66·67)\ 0·595\}=$					30·56	,,
[18]	$\dfrac{\sqrt{\{(P+\Pi v)^2+\Pi h^2\}}}{l-(z+g^1)}=$	p					Tons. Maximum pressure per square foot.
	$\dfrac{\sqrt{\{(24·274)^2+8·71^2\}}}{18-(0+7·60)}=\dfrac{25·79}{10·40}=$		2·48				,,
	$\dfrac{\sqrt{\{(64·97)^2+34·84^2\}}}{31-(1+10·15)}=\dfrac{73·72}{19·85}=$			3·71			,,
	$\dfrac{\sqrt{\{(132·05)^2+78·38^2\}}}{49·75-(2+14·39)}=\dfrac{153·56}{33·36}=$				4·60		,,
	$\dfrac{\sqrt{\{(234·38)^2+139·34^2)\}}}{73·71-(3+20·32)}=\dfrac{272·67}{50·39}=$					5·41	,,

CALCULATION OF MASONRY DAM OF 200 FEET HEIGHT.

DENSITY OF MASONRY 150 LBS. PER CUBIC FOOT (0·6696 TONS PER C. FT.).

No.	Description.	Symbol.	Imaginary Planes.				Notes.
			a.	*b.*	*c.*	*d.*	
[1]	$x=$		50	100	150	200	Feet.
	$y=\sqrt{\left(\frac{0\cdot05\,x^3}{\lambda+(0\cdot03\,x)}\right)}=$		27·11	70·71	121·14	175·41	,,
	$y=$ as a minimum $0\cdot6\,x=$		30	60	90	120	,,
	Width at top $=\sqrt{H}+2=16\cdot14=$	b					,,
	$y=$ at $\frac{1}{4}$ $H=\frac{H}{4}\times0\cdot72=$	a	36				,,
[2]	y as adopted $=$	y	36	70·71	121·14	175·41	,,
[3]	$z=$ from $\frac{H}{4}$ to 100 ft. depth a batter of 1 in 25 = ...	z	0	2			,,
	,, 100 ft. to 150 ft. ,, ,, 1 in 10 = ...	,,			7		,,
	,, 150 ft. to 200 ft. ,, ,, 1 in 5 = ...	,,				17	,,
[4]	Length of joint $=y+z=$	l	36	72·71	128·14	192·41	,,
[5]	Mean width of each section = ...		26·07	54·355	100·425	160·275	,,
[6]	Area of each section = [5] $\times h$ = ...		1303·50	2717·75	5021·25	8013·75	Square feet h = 50 ft.
[7]	Weight of each section 1 ft. wide = [6] $\times$ 0·06696 tons = ...	W	87·282	181·981	336·223	536·601	Tons.
[8]	Weight of masonry above each plane = ...	P	87·282	269·263	605·486	1142·087	,,
[9]	Vertical pressure of water on each section = $z_2-z_1\left\{x_2-\frac{x_2-x_1}{2}\right\}\times0\cdot02787$ tons = ...	w	0	4·18	17·42	48·77	,, weight of 1 c. ft. of water = 0·02787 tons.
[10]	Vertical component of water pressure on each plane	Πv	0	4·18	21·60	70·37	,,
[11]	Vertical press of masonry and water on each plane = [8] + [10] = ...	$P+\Pi v$	87·282	273·443	627·086	1212·457	,,
[12]	Horizontal water pressure $=0\cdot013934\,x^2=$	Πh	34·84	139·34	313·52	557·36	,, weight of 1 c. ft. of water in tons divided by 2 = 0·013934.

DETAILED CALCULATION OF MASONRY DAM OF 200 FEET HEIGHT—(*continued*).

No	Description.	Symbol.	Imaginary Planes.				Notes.
			a.	*b.*	*c.*	*d.*	
	Depth of centre of pressure $=\frac{2}{3}x=$	c	33·33	66·67	100	133·33	Feet.
[13]	Coefficient of sliding forces $=\frac{[12]}{[11]}=$	$\frac{\Pi h}{P+\Pi v}$	0·399	0·510	0·500	0·460	Limit = 0·76.
	Details of the determination of the Centres of Gravity, &c., by calculation.						
	$\frac{1}{3}\left(y_1+y_2-\frac{y_1 y_2}{y_1+y_2}\right)=$	g_y	13·67	27·62	49·07	74·97	Feet.
	$\frac{1}{3}\left(z_1+z_2-\frac{z_1-z_2}{z_1+z_2}\right)=$	g_z	0	0·67	2·48	6·35	,, vertical face.
	$gy-\frac{z_1+z_2\,(gy+gz)}{z_1+z_2+y_1+y_2}=$	gm	13·67	27·10	46·76	68·88	,, ,, ,,
	$gm-\frac{w\,(z_2-\frac{z_2-z_1}{2}+gm)}{W+w}=$	gmw	13·67	26·47	44·23	62·14	,, ,, ,,
	$W\times gm=$	m	1193·12	4931·66	15721·65	36961·01	Reservoir empty.
	Reservoir empty $=\Sigma m=$	M	1193·12	6124·78	21846·43	58807·44	Sum of moments.
	$(W+w)\,gmw=$	m^1	1193·12	4927·66	15641·50	36374·89	Reservoir full.
	Reservoir full $=\Sigma m^1=$	M^1	1193·12	6120·78	21762·28	58137·17	Sum of moments.
[14]	$\frac{M}{P}=$ Reservoir empty $=$	g	13·67	22·75	36·08	51·49	Feet.
[15]	$\frac{M^1}{P+\Pi v}=$ Reservoir full $=$	g^1	13·67	22·38	34·70	47·95	,,
[16]	$z+g=$	u	13·67	24·75	43·08	68·49	,, reservoir empty.
[17]	$y-\left\{g^1+(x-c\frac{\Pi h}{P+\Pi v})\right\}=$	u^1	15·68	31·33	61·44	96·79	,, reservoir full.
[18]	$\frac{\sqrt{\{(P+\Pi v)^2+\Pi h^2\}}}{l-(z+g^1)}=$	p	4·21	6·35	8·11	10·47	Tons, maximum press. per square foot.

The level of the water for the purpose of the calculations is the same as that of the top of the wall; there is therefore a small margin of safety by this practice. As the sill of the waste weir would be below the top level of the wall, the water of the reservoir would never rise to this level unless some stupendous and incalculable rainfall take place within the drainage area of the dam. It is safest, however, to allow for all contingencies, and it is consequently advisable to follow this practice in all cases.

In the Diagram (Fig. 1) it will be noticed that the line of resistance, reservoir empty, falls outside the middle third near to the base. This is of no practical importance in this case, firstly, by reason of its being only nine inches outside; secondly, at this depth the reservoir will probably always contain water, the sluice valve being somewhat above the lowest point in the dam, whilst the discharge pipe will always be considerably above that level. There will consequently be water in the lower basin of the reservoir, and the dam cannot be considered at this point as being empty. And, thirdly, a very small increase in the density of the masonry will tend to draw together the lines of resistance for both reservoir full and empty.

COMPARISON OF PROFESSOR RANKINE'S PROFILE WITH THE PRACTICAL PROFILE.

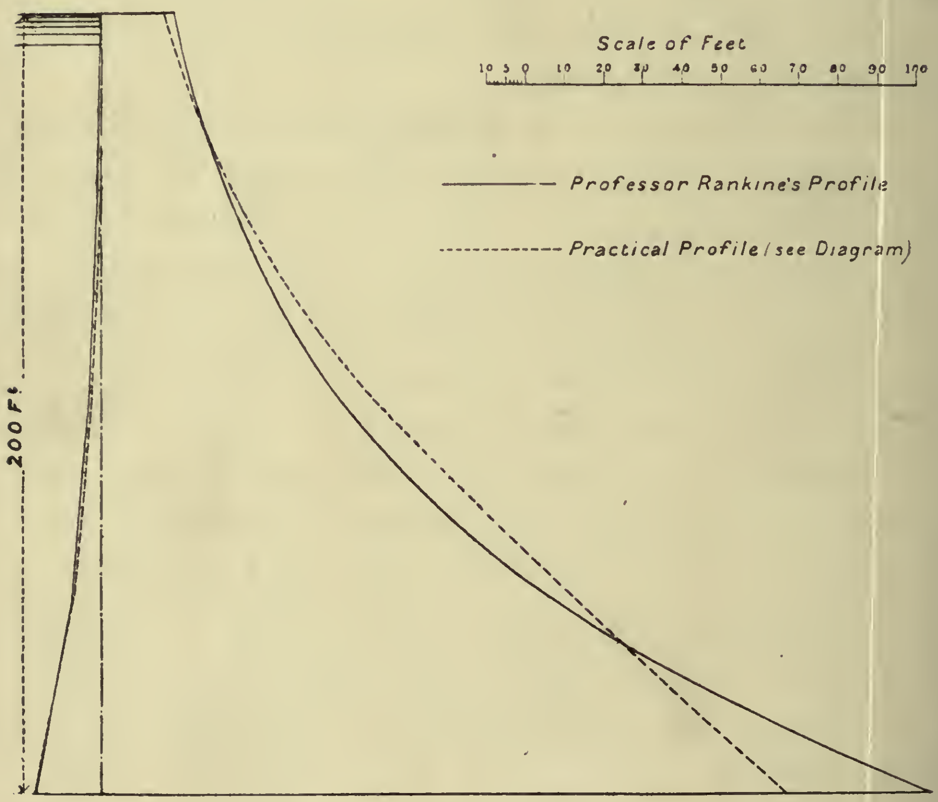


FIG. C.

CURVILINEAR DAMS.

Curved masonry dams are undoubtedly of greater strength than straight dams, as it is evident that on inclosing a narrow gorge with a curved dam, convex on the up stream face, it would act as an arch abutting on the sides of the valley, and in consequence of its form adapt itself to the variations of expansion and contraction. The inner face would not be exposed to tension due to any force acting upon it, whilst the uncertain expansive force of ice which might be formed on the surface of the reservoir would be amply resisted; but the advantage which this form has over that of a straight dam depends upon the radius of the curve. A long or short radius is indefinite, and would depend somewhat upon the height of the dam; under 300 feet may, however, be considered a short radius, and over 600 feet a long one; beyond this limit any advantage from the curved form would be doubtful.

It might be generally thought that by adopting this form material could be economised by reducing the sectional area of the profile. There is a general consensus of opinion, however, that the same principle should be followed in designing a profile, whatever the plan, unless a curve of less than 300 feet be adopted; as it is found impossible to state definitely

when a dam may be considered to act as an horizontal arch, the investigation resting on assumption, and being, withal, exceedingly complicated.

The board of experts—Messrs. J. P. Davis, J. J. R. Croes, and W. F. Shunk—who were appointed by the Aqueduct Commissioners to the Quaker Bridge Dam, reported upon the design of the profile as follows:—

"1. That, in designing a dam to close a deep, narrow gorge, it is safe to give a curved form in plan, and to rely upon arch action for its stability; if the radius is short, the cross-section of the dam may be produced below what is termed the gravity section, meaning thereby a cross-section or profile of such proportions that it is able, by the force of gravity alone, to resist the forces tending to overturn it, or to slide it on its base at any point.

"2. That a gravity dam, built in plan on a curve of long radius, derives no appreciable aid from arch action so long as the masonry remains intact; but that, in case of a yielding of the masonry, the curved form might prove of advantage.

"The division between what may be called a long radius and what may be called a short radius is of course indefinite, and depends somewhat upon the height of the dam. In a general way, we would speak of a radius under 300 feet as a short one, and one of over 600 feet as a long one, for a dam of the height herein contemplated.

"3. That, in a structure of the magnitude and importance of the Quaker Bridge Dam, the question of producing a pleasing architectural effect is second only

to that of structural stability, and that such an effect can be better obtained by a plan curved regularly on a long radius than by a plan composed of straight lines with sharp angular deflections.

"4. That the curved form better accommodates itself to change of volume due to change of temperature.

"While chance of the rupture of the masonry of the dam by extraordinary forces, if built on the profile herein recommended, is, in our opinion, very remote, yet it exists; and because it exists, and because the curved form is more pleasing to the eye, better satisfies the mind as to the stability of the structure, and more readily accommodates itself to changes of temperature, we think that it should be preferred in any case where it would cause no great addition to the cost.

"In comparing different locations of the dam, in order to discover the one which combined most effectively the advantages of economical construction and pleasing effect, we were confronted with the fact that—our calculations indicate that—in a dam built upon a curved plan of large radius the bottom down stream toe pressures are increased beyond those in a straight dam of the same section, in consequence of the length of the toe being less than the length of the face to which the pressure is applied. This increase of pressure is not exactly proportional to the decrease of length of toe, but it is of such magnitude that it should not be neglected in designing the section of the dam; and it involves the necessity of increasing the mass of masonry in a certain proportion to the radius of the curvature.

"*Conclusions.*—In view of the premises, and pursuant to our instructions, and believing that the dam will be more pleasing in appearance and better able to resist extraordinary forces if built on a curved plan, and bearing in mind that an excessive thrust in the direction of the curve cannot be produced until the force of gravity has been overcome, and that the profile is so proportioned that more than twice the greatest pressure exerted by any conceivable ordinary force is necessary to overcome the resistance of gravity, we recommend the adoption of the profile (Fig. D.), and of a curved plan on a radius of about 1,200 feet, as hereinbefore described, and we advise that the exact line be determined after further borings shall have established the most desirable location on the conditions prescribed.

"It should be added, in conclusion, that the form and dimensions herein recommended for adoption are prescribed on the assumption that the structure shall be well founded, and that its material and workmanship shall be of the first class in their several kinds."

PROFILE OF QUAKER BRIDGE DAM,

designed by Board of Experts.

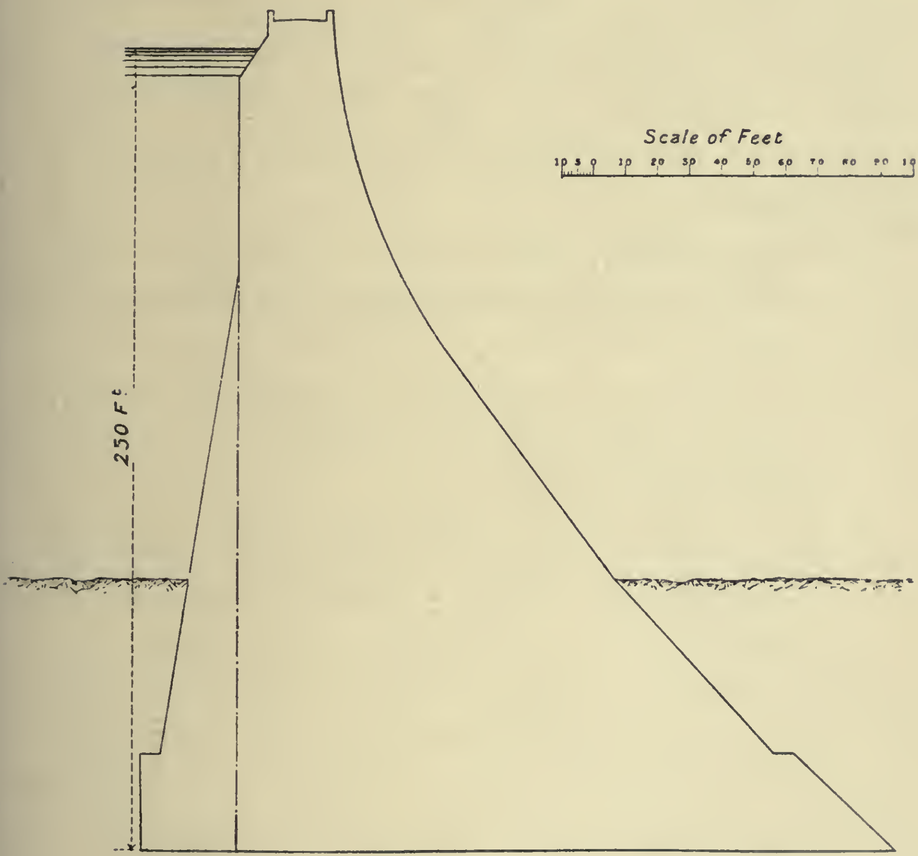


FIG. D.

WASTE WEIRS.

The waste weir of a dam is of great importance, although not to such an extent as for earthwork dams; an ample allowance must, however, be given. To definitely fix what actual width should be allowed for safety, three points must be taken into consideration:—

1. The maximum flow of a stream is never equal to the quantity of water falling over the catchment area.
2. The reservoir itself acts as an accumulator to the extent of the rise of the water over the sill of the weir.
3. The measured height of water above the overflow level due to storms is further raised by wave action.

The capacity of the reservoir is up to the sill of the weir. Any rise above this level is therefore what the weir discharges *plus* the water accumulated by that height; and, as considerable depth of weir increases the amount of masonry along the whole top of a dam, it is usual to make the width considerable to obviate this objection, as well as the danger from choking by trees and timber that may be brought down by the flood.

The discharge of a waste weir with paved apron may be calculated from the following formula:—

$$V = \sqrt{\frac{K\,D}{S}} \qquad Q = A\,V$$

where

V = Mean velocity in feet per second.

D = Mean hydraulic depth = $\frac{\text{Sectional area of flow}}{\text{Wetted perimeter.}}$

S = Slope or length of channel to fall of 1.

K = 8,500.

A = Sectional area of flow.

Q = Cubic feet of water discharged per second.

A table given by Mr. W. K. Burton, C.E., in his admirable work on "The Water Supply of Towns," and based on one by Fanning, will be found useful, the depths to width being safe in countries not liable to tropical rains:—

Catchment area.	Length of weir.	Depth of water over weir.
200 acres.	16 feet.	1 foot 5 inches.
400 ,,	20 ,,	1 ,, 10 ,,
1 square mile.	25 ,,	2 feet.
2 ,, miles.	32 ,,	2 ,, 5 inch.
3 ,, ,,	39 ,,	2 ,, 7 inches.
4 ,, ,,	44 ,,	2 ,, 9 ,,
6 ,, ,,	54 ,,	3 ,,
8 ,, ,,	61 ,,	3 ,, 3 ,,
10 ,, ,,	68 ,,	3 ,, 6 ,,
15 ,, ,,	83 ,,	3 ,, 9 ,,
20 ,, ,,	95 ,,	4 ,,
25 ,, ,,	105 ,,	4 ,, 2 ,,
30 ,, ,,	116 ,,	4 ,, 4 ,,
40 ,, ,,	133 ,,	4 ,, 7 ,,
50 ,, ,,	149 ,,	4 ,, 10 ,,
75 ,, ,,	183 ,,	5 ,, 3 ,,
100 ,, ,,	212 ,,	5 ,, 8 ,,

For intermediate areas the length and depths may be taken as proportionate.

The effect of wave action on a well constructed masonry dam may be ignored, but provision should be made for the free break of the waves over the top. Any protection wall along the top is objectionable, as it receives the full blow of the waves. A free top with a slope to the back to allow the water to run freely, with specially prepared drains at the base to convey the water into the valley below, is perfectly safe.

If the surface area of the water impounded be great, it may be necessary and advisable to calculate the height of wave to which the dam might be exposed, and for that purpose Stevenson's formula will be found useful. It is based on the fact that the maximum height of a wave is a function of the "fetch" of the reservoir, the fetch being the longest straight line that can be measured from any part of the dam to any part of the shore of the reservoir when full :—

$$H = 1{\cdot}5\sqrt{D} + (2{\cdot}5 - \sqrt[4]{D}).$$

H = Height of wave in feet.

D = Fetch in miles.

It is obvious that, should the reservoir be of very great length, so as to cause high waves, the waste weir must be increased, or otherwise too large a volume of water will dash over the top, which will undermine the base and endanger the structure.

VALVE TOWER AND SCOUR SLUICES.

There are many methods adopted to supply water from reservoirs. For low dams a cast iron tower made in segments and bolted together, with inlets at various heights, answers the purpose very well; in other cases a simple bronze valve fixed into the discharge pipe, with raising and lowering gear actuated from the top of the wall, with movable cage or screen over the valve to prevent obstruction or damage, is of small cost and effective. Simplicity of construction is essential, and for high dams no better form can be employed than a round masonry tower starting from the toe of the inner face of the dam, connecting with a gallery that passes through the dam constructed for the purpose of receiving the discharge pipes, which would rise in the valve tower, where at various heights branches are attached that are controlled by exterior as well as interior valves.

This system permits of any repair being done without loss of water or danger to workmen. From want of forethought in designing the discharge arrangements for reservoirs, not infrequently divers have had to be employed to either remove obstruction or adjust the valves. The diameter of the tower is governed by the size of the discharge pipes which it is to contain, allowing for descending, or ascending and manipula-

tion of the various heavy pieces during erection and repair.

The tower must be built of well cut and bonded stone, as it will be subjected to considerable pressure, and special care must be taken that a secure connection is made to the discharge gallery.

For estimating the diameter of pipe required for a known supply derived from different heads of water, Eytelwein's formula may be employed :—

$$W = 4{\cdot}71 \sqrt{\frac{D^5 H}{L}} \qquad\qquad D = 0{\cdot}538 \sqrt[5]{\frac{L W^2}{H}}$$

where

D = Diameter of pipe in inches.
H = Head of water in feet.
L = Length of pipe in feet.
W = Cubic feet of water discharged per minute.

In no case should the discharge pipe be at the lowest part of the valley, space being required for silt, and at this point is generally built into the wall a large scour pipe with deep and heavy flanges, to form a perfect bond with the masonry of the dam, and prevent the possibility of any percolation of water between it and the pipe. A heavy bronze sluice valve will cover the face of this pipe, actuated from the top, and an arrangement may be required to agitate the sludge around its mouth, the pressure of the water when once a blow is started being sufficient to clean the bottom of any accumulated silt. It is the practice of some engineers to leave a well in the centre of the dam, connection being made through the wall to the face

at various heights, to which the discharge pipe is attached, the scour pipe being at the bottom, a gallery from the well to the outer face being utilised for the double system. This method cannot, however, be recommended, by reason of its weakening effect upon the stability of the dam.

The Alicante Dam, which was built during the years 1579 to 1594, and ascribed to Herreras, the famous architect of the Escurial Palace, is in a deep gorge, being 134½ feet high, and its length at the top only 190 feet. The plan is curvilinear, having a radius on the up stream side of the crown of 351 feet. In Mr. E. Wegmann's valuable work on "The Design and Construction of Masonry Dams," the following descriptive remarks are given of the scouring arrangements :—

"Owing to the steep declivity of the beds of most Spanish streams and to violent storms, large quantities of fine material, which has been pulverized by the action of the water, are deposited in the storage reservoirs. Unless some means were provided to remove this sediment it would soon fill these basins completely. In 1843, when the Alicante reservoir had not been cleaned for fourteen years, a bank of sediment 75 feet high at the dam had been deposited. Since then the reservoir is scoured once in four years, the maximum height of the material deposited during that time being 39 to 52 feet.

"Long experience has taught the Spaniards the best method of removing these deposits, namely, by means of scouring galleries. In the Alicante Dam such a

gallery is placed in the axis of the valley, crossing the dam in a straight line from face to face. Its up stream opening is 1·8 metres wide by 2·7 metres high. The gallery has this cross-section for the first 2·7 metres of its length, and is then suddenly enlarged to a section of 3 metres width by 3·3 metres height. After this the cross-section is increased gradually, so that it is 4 metres wide by 5·85 metres high at the down stream face of the dam. By this increase in the cross-section of the gallery, which takes place in all directions, the material forced out of the reservoir by the water pressure can expand freely, and does not obstruct the channel through the dam.

"The mouth of the scouring gallery is closed simply by a timber bulkhead formed as follows: First, a vertical row of beams about one foot square is placed, their ends projecting into horizontal grooves cut into the solid masonry; the last beam which closes the row is somewhat shorter than the rest, and enters only the lower groove. After the joints between the beams have been calked a second row of similar timbers is placed directly behind the first row, they are laid horizontally, their ends being secured in vertical grooves in the sides of the gallery. Behind the second row three vertical posts are placed, each of which is firmly held by two inclined braces whose lower ends project into the floor of the gallery.

"The banks of sediment formed in the reservoir acquire considerable consistency if left undisturbed for a few years. When it is necessary to scour the reservoir it becomes thus possible to remove gradually the

timbers at the inlet of the gallery without much danger to the workmen. The timbers of the course next the reservoir are cut, one by one, with the greatest precaution. Should any movement be perceptible in the deposited material the men abandon their work, which will be quickly completed by the water pressure.

"Generally, however, the opposite to this takes place. The sediment forms a solid bank in front of the scouring gallery, and does not move until a hole has been made through it from the top of the dam. The heavy iron bar which is employed for this purpose at the Alicante reservoir is 0·2 feet square, 59 feet long, and weighs about 1,100 lbs. It is worked by means of a windlass and pulleys. When a hole has been pierced through the bank of sediment the scouring action begins, first slowly, but soon gaining a tremendous force. All the sediment, except that in remote parts of the reservoir, is forced through the scouring gallery, the noise made by this violent action being like that of cannons. Nothing remains for the workmen to do but to shovel the remaining sediment into the current. Sometimes the deposit has become so hard that it must be undermined from the scouring gallery before a hole is pierced in it by the long bar. The total cost of scouring the reservoir, including the loss of timbers which are cut, amounts to only £10.

"Although the method of cleaning the reservoir seems at first sight rather primitive, yet, on second thoughts, it will be found to be practical. Where such deep deposits are made gates are out of the question, as they

would have to be frequently opened to prevent their becoming useless, and would thus cause a considerable loss of water. While the scouring operation as carried on at the Alicante Dam certainly involves danger to the workmen, accidents are very rare."

FOUNDATIONS.

Having calculated the requisite profile and completed the design of the dam, it becomes necessary to settle upon the form of foundations that shall be adopted, and in what way all possibility of filtration shall be prevented. However carefully this may be schemed out, modification may become necessary during the progress of the work. Should any unexpected variation in the condition of the rock present itself in opening up the foundations, all loose and weathered portions of the rock will require to be stripped off to the solid for the whole width of the dam at its base and cut into horizontal beds. There will, however, when this is done, still be small cracks, false seams, &c., left, which though probably not apparent to the eye, are still there, and possibly of such a length as to pass from the face to back of dam. For further securing the foundations against percolation a trench should be cut of not less than ten feet width at the top and three feet at the bottom, being of such a depth as to completely cut out any false seam, spring, or vein of soft material, clay, &c.; the relative position of this trench being in the centre of the base-width of dam, or a third of the width from the inner toe, and parallel to it for the whole length of the foundations. The position of this trench

in high dams is of importance, as the upthrust from the pressure of water tends to counterbalance the downthrust of the masonry, which may seriously affect the stability. In some dams this apron or valance, being excavated along the inner toe of the wall, leaves the whole foundation dry and free from any force which the water might exert upon the base when the reservoir is full.

In the lower portion or centre of the valley or gorge water will be met with, which must be concentrated and dammed back by well calked timbering or other methods, that the foundation material, whatever it may be, can be built into position free of water. Wherever a percolation in the rock is observed the trench must be excavated below that point, so that the spring may be seen issuing above the lowest part of the foundation. There is always greater security in working in the centre of the valley than in rising on each side, as porosity is made evident by the water and moisture. The experience gained, however, by close observation of the condition of the rock at the lowest level will guide the engineer as to the necessary depth to cut the trench in the higher portions.

The foundation rock, before building operations begin, should be well cleaned by the use of brushes made of steel wires, and washed by a stream of water from a hydrant or pump that will give force enough to clean the crevices of the rock of all sand or dirt and assist the effect of the brushes.

Blasting operations in the foundations should be

SECTION OF BASE OF DAM, SHOWING FOUNDATIONS.

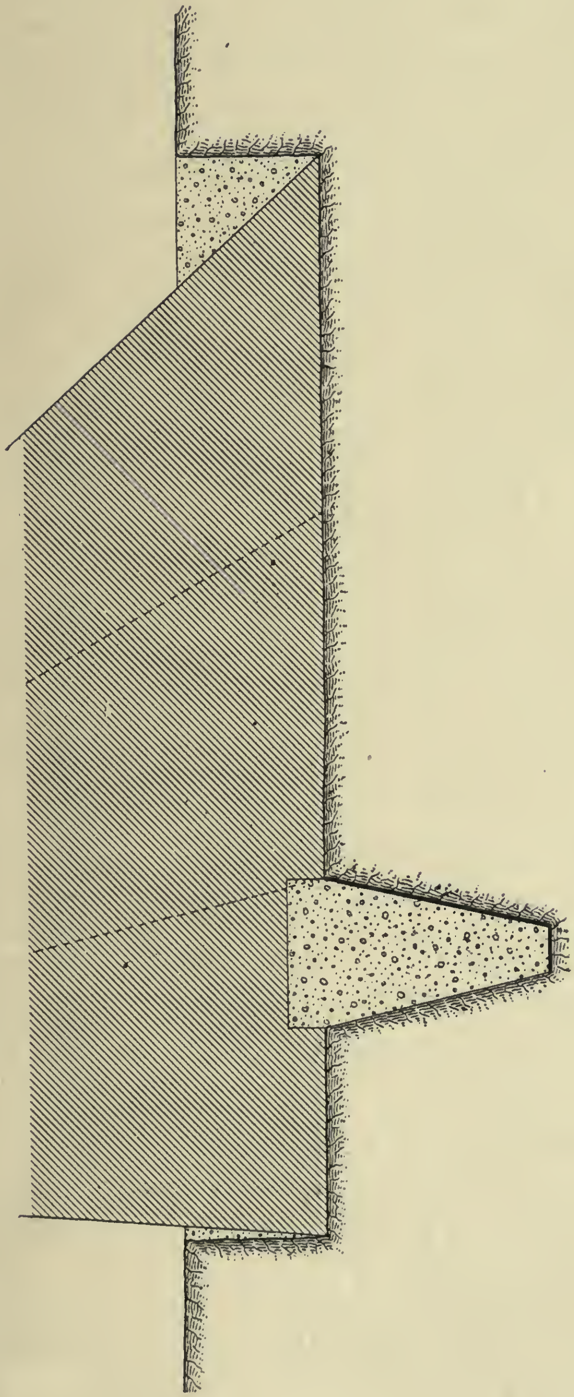


FIG. E.

Scale, one-sixteenth of an inch = one foot.

conducted with great care and supervision, and the trench cut without the use of any kind of blasting material. The inner portion of the basin, should it appear necessary, may be cleared of subsoil, and seams containing clay, &c., cleared out and sealed with cement mortar. This is a further security against percolation, though a tedious and expensive operation, which rarely has to be resorted to, and should not be done to save excavation under the base of the dam, as it will in any case only prevent considerable leakage, but not percolation; whereas, if the trench be sunk deep enough, all filtration will be cut off.

The Puentes Dam in Spain, which was 164 feet high, was totally destroyed eleven years after it was built from having faulty foundations. It was originally intended to found the wall entirely on rock, but in the centre of the valley a deep pocket of subsoil was encountered, and it was decided to build the wall at this point on a pile foundation. This was built very securely, and would have answered the purpose if the water had not risen above eighty-two feet, at which level it was maintained during the eleven years. In April, 1802, however, the water rose to an elevation of 154 feet above the base of the dam, and the foundations gave way. It was noticed, just before the wall burst, that on the down stream side water of a red colour was issuing in great quantities. In a short time an explosion occurred, and enveloped by an enormous body of water, the piles and timbers which formed the pile-work of the foundation and apron were forced upwards; the volume of water that escaped

was so considerable that the reservoir was emptied in the course of an hour; 608 lives were lost, and property amounting to £210,000 was destroyed.

We have here demonstrated the important fact that a high masonry dam, however well proportioned, can only be safe if founded entirely on solid rock.

CONSTRUCTION.

In construction we have the choice of four classes of masonry :—

1. Cut-stone masonry (block masonry).
2. Rubble masonry.
3. Concrete.
4. Rubble or concrete with cut stone (ashlar) facings.

1. The first would seem to possess the best and most solid material for the purpose, and be of great strength. Its cost, however, is between three and four times that of rubble, and it offers only about twice the strength.

2. Rubble masonry is easily worked, lends itself safely to the treatment of unskilled labour, possesses ample strength, and is readily adaptable to any form of profile.

3. Concrete has all the advantages of rubble masonry; though considered to be too pervious, it has, however, been used successfully, and is undoubtedly the most easily worked of these three classes of masonry. Rubble masonry is, after all, only concrete with a large aggregate.

4. Rubble or concrete with cut stone facings cannot be recommended, in consequence of its liability to uneven settlement.

Rubble masonry is, undoubtedly, generally the most convenient to use, and probably the most secure against percolation. Regular horizontal courses must be avoided, the great object being to form a monolith as homogeneous as possible. The stones to be employed may be from half a cubic foot, as in the Tausa Dam, to six or seven cubic feet, and should be laid with their natural bed horizontal. Whatever strength of mortar may be used, a certain amount of leakage will always take place when the reservoir is first filled. In a well constructed dam this leakage only shows itself as a dampness on the back face, and generally disappears in the course of six months or a year.

Great care should be exercised in the selection of the stone that is to be employed in the construction. It will, however, be generally found, as before stated, that adhering to 150 lbs. per cubic foot as the density will insure a good class of stone being used. A few tests may, however, be necessary, and we may therefore note the following:—

The carbonic acid which exists in the pure atmosphere of the country decomposes any stone of which either carbonate of lime or carbonate of magnesia forms a considerable part.

The oxygen of ordinary air will also act upon a stone containing much iron.

An examination of the stone may be made by magnification. A recent fracture when seen through a magnifying glass should be bright, clean, and sharp, with the grains well cemented together. A dull earthy appearance betokens a stone likely to decay.

The amount of water a stone will absorb is also an indication as to its quality, the best stone absorbing the least quantity of water. This can easily be ascertained by immersing the stone it is required to test in water for twenty-four hours, and noting the weight both before and after immersion. By immersing small pieces of stone in a concentrated boiling solution of sulphate of soda (Glauber's salts), and then hanging them up for a few days in the air, the salt will crystallize in the pores of the stone, forcing off pieces from the corners; and should the stone have open seams or joints, it will detach large fragments. By weighing the stone used, both before and after this test, the amount of forced disintegration can be ascertained.

Carbonate of lime or carbonate of magnesia can be easily detected by dropping on the surface of the stone a very small quantity of hydrochloric acid, when an intense effervescence will be noted if there be present a large proportion of either carbonate.

In quarrying stone for building purposes the least amount of blasting is preferable, the stone becoming greatly shaken by any sudden and violent explosion, and the waste produced proportionally large. All stones intended for building purposes should be placed in the work with their natural beds at right angles to the pressure that will come upon them. This should therefore govern the mode of operation in winning the stone.

In testing the resistance to crushing of various stones care must be taken that the samples used are not too small. The result obtained will generally

indicate somewhat more than the real strength of the material, in consequence of the fracture taking place by shearing on a plane inclined at a slope having one-and-a-half rise to one of base; the experiments should therefore be made on prisms whose heights are about one-and-a-half times their diameters. Basalts, primary limestone, slates, &c., give way suddenly; other stones begin to crack under a-half to two-thirds the crushing load.

It is generally laid down that the compression to which a stone should be subjected in a structure should not exceed one-tenth of the crushing weight as found by experiment. The weakest sandstones that exist will bear a compression of 120 tons per square foot. The resistance of ordinary building stone ranges from 140 to 500 tons per square foot; granite and traps rising as high as 700 or 800 tons per square foot.

It is important that the stones used on the face or back of the dam should contain no soft patches or inequalities, but be specially selected, and that the whole of the stone from the quarry used in the work should be stacked and exposed to air action for a few weeks before being employed for building.

We have now to consider the class of mortar and its composition that is to be used for cementing together the stone which is to be employed in the construction of a dam. It should be remembered that the presence of moisture in hydraulic limes and cements favours the continuance of the formation of the silicates, &c., commenced in the kiln, and that their setting action is prematurely stopped if they are allowed to dry too

quickly. It is therefore of the utmost importance, especially in hot climates, that the stones to be embedded in the mortar should be well wetted, so that they will not absorb the moisture from the mortar, and also to remove the dust from their faces, which would prevent the mortar from adhering. Any portion of the dam that is left for a few days during construction in order to bring up other portions to the required height should not be allowed to dry, but water be constantly thrown upon its surface. The mortar should be as stiff as it can be conveniently spread, the joints all being well filled, and a specially selected spalls from the waste of the hardest stone from the quarry be firmly wedged in, so that the mortar is pressed and squeezed into all spaces round and about the joints and voids of the building stone. Grouting should never be used except with large cut blocks, when it is preferable to force the mortar into the joints with specially prepared implements.

In frosty weather all building must be stopped, as well as during heavy rains, as with frost the expansion of water in the mortar will disintegrate it, prolonged frosts necessitating sometimes the removal of the last layer built so as to secure a joint free from any suspicion of disintegration. Rain, on the other hand, immediately spoils the mixture of the mortar by washing away the cement covering the sand, and thereby destroying its adhesive power.

Stoppages caused by rains, frost, cessation of work on Sundays or holidays are likely to be productive of leakage along the joint of the fresh work. This can

be obviated by the use of bags and tarpaulins as coverings, as a protection against rain and frost, and by not filling the joints between the stones with mortar—or, in other words, not bringing the work up flush each day. There is a minimum of area between the mortar which is set and the fresh mortar applied when worked in this way.

In placing large stones by the aid of a crane it is very necessary to leave ample width between them, as a slight touch from a heavy stone might break the already formed joint of the stone previously set in position.

It is extremely unsafe to use lime mortars for masonry dams, they being, unless eminently hydraulic, unable to resist any pressure of water. In some cases low dams have been built with lime mortar, with the face mortar containing a proportion of cement; the face joint being afterwards carefully pointed with cement and a specially selected fine sand. This practice cannot, however, be recommended for high dams, as the setting of the lime mortar requires a lengthy period, whilst it is very doubtful if the interior ever hardens. It may also happen that water is required to be accumulated in the newly formed reservoir immediately after the completion of the dam, which would be a highly risky proceeding if an unhydraulic lime mortar were used.

Some curious facts may be mentioned, not only to show the influence of a large body of masonry in retarding the solidification of the mortar in the interior, but also the danger of using rich limes

in cases where such masses are necessary. Amongst them is the fact, cited by General Treussart, concerning the bastions erected by Vauban in the Citadel of Strasbourg in the year 1666. In the interior the lime, after 156 years, was found to be as soft as though it were the first day on which it had been made. Dr. John, also, mentions that, in demolishing a pillar nine feet in diameter in the Church of St. Peter at Berlin, which had been erected eighty years, the mortar was found to be perfectly soft in the interior. In both cases the lime used had been prepared from pure limestone.

As the site of the works for the formation of a reservoir is generally some distance away from any town or habitation, the cost of carriage may affect very seriously the cost of the scheme of water supply. Not unnaturally the district in the immediate neighbourhood of the site of the reservoir will be diligently searched for limestone of a quality to supply the cement required for the construction of the dam. A few rough tests may therefore be applied, should a limestone be found, to see if it be likely to furnish a hydraulic lime or cement. Such a stone, if serviceable, will generally have an earthy texture, and will weather to a brown surface. Acid, when applied in a few drops, will not cause such an effervescence as upon purer limestone. When breathed upon or moistened a clayey odour is emitted from the stone.

The best plan, however, is to burn a little in a small experimental kiln, and to afterwards observe

the slaking and the behaviour of pats made from the paste.

The proportion of clay or other constituents in a limestone influences very greatly the setting properties of hydraulic lime without drying or the access of air.

Vicat, therefore, subdivided limes into the following three classes:—

Name of Class.	Percentage of clay associated with Carbonate of Lime only or with Carbonate of Lime and Carbonate of Magnesia.	Behaviour in slaking after being wetted.	Behaviour in setting under water.
Feebly Hydraulic.	5 to 12 per cent.	Pauses a few minutes, then slakes with decrepitation, development of heat, cracking, and ebullition of vapour.	Firm in 15 to 20 days. In 12 months as hard as soap — dissolves with great difficulty, and in frequently renewed water.
Ordinarily Hydraulic.	15 to 20 per cent.	Shows no sign of slaking for an hour or perhaps several hours—finally cracks all over, with slight fumes, development of heat, but no decrepitation.	Resists the pressure of the fingers in 6 or 8 days, and in 12 months as hard as soft stone.
Eminently Hydraulic.	20 to 30 per cent.	Very difficult to slake—commences after long and uncertain periods—very slight development of heat, sensible only to touch—very often no cracking or powder produced.	Firm in 20 hours—hard in 2 to 4 days—very hard in a month—in 6 months can be worked like a hard limestone, and has a similar fracture.

The method of testing of limes may be expedited by first taking a small basket full of the lime it may

be desired to test and immersing it in pure water from six to ten seconds, allowing the uncombined water to run off. Before cracking and falling to pieces begins, fill a vase with the lime, pouring in water by the side of the vase, that it may flow freely to the bottom, whence it will be absorbed by the lime that is in an advanced state of chemical action. Frequently stir and add water, not to flood, but to bring the lime to the consistency of a paste; leave until the inert particles have completed their action; this is announced by the cooling of the mass, which may require three or four hours or more. When all action has ceased beat up again, and add water, if necessary, to produce the consistency of potter's clay. Take a vase of this paste, filling it even with the top, and immerse the vase in water, taking note of the hour, day, month, and year in which it was immersed.

From the above table it will be seen that an artificial hydraulic lime may be made by moderately calcining an intimate mixture of a fat lime with as much clay as will give the mixture a composition like that of a good natural hydraulic limestone, of which the product should be a successful imitation.

A soft material like chalk may be ground and mixed with the clay in a raw state. Compact limestone, on the other hand, requires burning and slaking in the first instance—this being the most economical way of reducing it to powder—then mixing with the clay and burning a second time.

We have seen from the foregoing that lime mortar should not be used, and that hydraulic limes may be

difficult to obtain in the district in which the works may be situated. It may consequently be assumed that imported cement will be used, and if that be the case all liability to doubt as to the permeability of the wall will be considerably diminished. It is therefore necessary to enter somewhat fully into the testing, manipulation, and porosity of various mixtures of cement with sand.

Portland cement differs very considerably in its characteristics and action. It can be manufactured more cheaply when under-burnt, because then a greater bulk of cement is produced with a given quantity of material, and it requires less fuel and less grinding; it also sets more quickly, but never arrives at the same ultimate strength as a burnt cement. Under-burnt cement contains, moreover, an excess of free quick-lime, which is apt to slake in the work and cause great mischief. This may be remedied by exposing the cement and allowing these particles to become air-slaked.

A slight difference in the manufacture may make a great difference in the character of the material, and rigid testing is necessary in order to secure the best cement.

Fineness of grit may be roughly tested by rubbing it between the fingers, or accurately by passing it through a sieve with meshes of known size.

The experiments of Messrs. Grant, Colson, and others show that when used neat a coarse grained cement is stronger than one finely ground; when mixed with sand, however, the finely ground cement

makes stronger mortar than the other, the difference in its favour being greater as the proportion of sand in the mortar is greater. Where fineness of grit is alluded to in specifications, as it always should be, 14,400 meshes to the square inch is frequently specified, though the Metropolitan Board of Works used to specify, as well as a few engineers, that not more than ten per cent. by weight should be rejected by a sieve of 5,800 meshes to the square inch ; and there seems no doubt that this requirement, which is estimated to add only one-tenth to the cost of the cement, is a very desirable one to enforce. Good makers, however, generally grind their cement fine, and there need be no apprehension on this point. When the cement is obtained from recognised makers it is best to specify a cement that will pass a sieve with 14,400 meshes to the square inch, with not more than 10 per cent. residue, for reasons given further on.

Great care must be taken that finely ground cement is not lightly burnt, to prevent which the weight, or, better still, the specific gravity, of the cement should be tested. The weight of a cement is generally specified per striked bushel, it being considered that good weight per bushel is a sign of thorough burning; but it is obvious that the weight is greatly influenced by the degree of fineness to which the cement is ground, also by the degree to which it has been aerated, and by the way in which the measure has been filled. The weight per bushel is therefore of little value.

The effect of fine grinding upon weight is shown

in the following results, obtained by Messrs. Currie and Co., of Leith :—

Meshes per square inch of sieve.	Percentage retained by sieve.	Weight of cement per bushel in lbs.	Weight of cement per cubic foot in lbs.
2,500	10	115	90
3,600	10	112	87
5,500	10	109	85
14,400	10	104	81
32,000	10	98	76

As the weight is therefore no reliable gauge of the quality of a cement, it is better to require a certain specific gravity to be given, which cannot vary with the different degrees of fineness of grit.

Mr. Grant, the Resident Engineer of the Metropolitan Main Drainage Works, found that the specific gravity of cement supplied by the best English manufacturers slightly exceeded 3·0, an inferior cement not being more than 2·8, whilst experiments showed the specific gravity of differently burnt cements to be as follows:—

Light burnt, 3·130.
Hard ,, 3·134.
Medium ,, 3·131.

And his specification for specific gravity was not less than 3·1.

The specific gravity of cements can be easily ascertained by using Keate's Specific Gravity Bottle (Fig. F, next page), which is described by Mr. Grant in the Min. Inst. C.E., vol. LXII.

The bottle consists of two bulbs, the lower somewhat exceeding the upper in capacity. The exact capacity of the lower bulb is of no importance. On the neck between the bulbs is a file mark, *b*; on the neck of the upper bulb is a similar mark, *a*.

The capacity of the upper bulb between the marks *a* and *b* must be accurately determined, and may conveniently be either 500 or 1,000 grains, in water measure, at 60° Fahr.

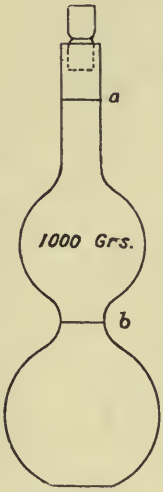


FIG. F.

In ascertaining the specific gravity of a solid in small fragments—small shot, for example—the following is the mode of procedure: fill the bottle with distilled water up to the mark *b*, accurately counterpoise the bottle so filled in a balance; drop the substance *of which the specific gravity is to be taken* carefully and gradually into the bottle until the water rises from *b* to *a*. Ascertain exactly the weight of the material so added. If the capacity of the upper bulb be 1,000 grains of water the weight of the material required to raise the water from *b* to *a* is its specific gravity; if the capacity of the upper bulb be 500 grains of water the weight of the substance added must be multiplied by 2, which will give the specific gravity.

The principle of the apparatus is very simple. The capacity of the upper bulb is an exact measure of distilled water, and when the water is raised from *b* to *a* by dropping a solid into the bottle the bulk of that solid, equivalent to the given volume of the distilled water, is ascertained, and the relation between the weights of the two is given by the weights of the substances added, which is either the specific gravity direct, if the capacity of the bulb be 1,000 grains, or it can be ascertained by multiplying the weight of the solid by the number which represents the part of 1,000 represented by the capacity of the bulb, &c.

The only precautions to be observed are that the air, which is apt to cling somewhat to the solid matter when dropped into the liquid, is carefully removed, and that if a very volatile liquid be used in the place of water the bottle should be stoppered or corked to prevent evaporation.

Besides the test for specific gravity, which, as has been pointed out, is of more importance than specifying the required pounds per striked bushel, other additional tests may be made which will give an indication as to some important qualities of the cement before using.

A thin glass bottle is filled with neat cement; if after some days it becomes set, and the bottle remains uncracked, it may be considered that the cement is not too hot. If the cement has shrunk within the bottle it is probably under-burnt; the shrinkage can be detected by pouring in a little coloured water. By filling a piece of glass tubing 18 inches long with neat cement, shrinkage can be very easily noted in a few days. Expansion and cracking may be tested by exposing a few well made pats of neat cement to hot steam, or by placing them in boiling water, after setting over night; five hours in hot steam of 200° Fahr. or over will be found sufficient to detect the slightest tendency to expand or crack.

All cements possessing a very high tensile resistance may be suspected of containing an excess of lime, and therefore, to prevent blowing, require considerable air-slaking or cooling.

In the gauging of cements great care must be

exercised. It is usual to specify that each cubic foot shall contain 87 to 90 lbs., and to obtain 90 lbs. per cubic foot some difficulties may be encountered in consequence of the extreme fineness to which cements are now ground; weight should, however, be insisted upon in the specification, to insure water-tightness. By using a conveniently shaped hopper with valve and spout, set at an angle of 45°, the required weight per cubic foot may be obtained; but it is necessary that the gauge box shall be of one cubic foot only—that is to say, measuring 12 inches square by 12 inches depth. If, for the purpose of saving time, double the quantity is used for twice the cube of sand, the gauge box must be increased by the square, the depth being constant. A box or vessel of 12 inches square and 24 inches deep will hold 14·2 per cent. more than twice the weight held by a cubic foot from settlement by its own weight, whilst gauge boxes of less than a cubic foot will contain proportionately less than the true equivalent of 87 to 90 lbs. per cubic foot.

It is advisable, from what has been previously mentioned, that the specified tensile strength shall not be placed too high, and it is better to require a moderate tensile strength, such as 300 to 350 lbs. per square inch, observing carefully the increased resistance to breaking by age.

Tests of cement mixed with sand to be used in the work are very desirable, but the length of time required, being not less than 28 days, renders it very difficult to carry out. It is also almost impossible to insure that

the whole of the sand used be of uniform composition and quality as regards sharpness, surface of grains, &c. There can be no doubt, however, that this test will give more satisfactory information than can be obtained by testing the cement neat.

The test for tensile strength can be obtained by the use of a machine for that purpose, the moulds for making the briquettes being slightly rubbed with a greasy rag before putting in the paste. In making the neat paste not more than 20 to 25 per cent. in bulk of pure water. must be used, and the pressure applied by the machine at the rate of 400 lbs. per minute. There are several classes of machines in the market, and in making a choice preference should be given to one that is conveniently geared to this speed. Generally there are difficulties experienced in working the machine at so slow a speed, the impulse being jerky when applied slowly by the hand. A difference of 25 per cent. can be obtained in tensile strength of neat cement between slow and quick speed, 800 lbs. being applied in less than one minute increases the true breaking weight by at least 25 per cent.

Tests of compression are also of great importance, but the apparatus required is cumbersome, and these tests are therefore rarely carried out. It may be generally assumed that resistance to compression is about twenty times that of the tensile strength.

The following table will indicate the tensile strength per square inch of Portland cement mortar of various

mixtures as compared with the same class of cement neat:—

Age and time immersed.	Proportion of clean pit sand to 1 cement.					
	Neat cement.	1 to 1.	2 to 1.	3 to 1.	4 to 1.	5 to 1.
1 week.	445·0	152·0	64·5	44·5	22·0	
1 month.	679·9	326·5	166·5	91·5	71·5	49·0
3 months.	877·9	549·6	451·9	305·3	153·0	123·5
6 ,,	678·7	639·2	497·9	304·0	275·6	218·8
9 ,,	995·9	718·7	594·4	383·6	—	—
12 ,,	1075·7	795·9	607·5	424·4	317·6	215·6

The superiority of fineness to strength is fully shown from the following data, given by Mr. Grant:—

Age of Briquette.	Neat.		Three of sand.		Five of sand.	
	10·2 per cent. residue on a sieve of 2,580 meshes per square inch.	Sifted so as to pass all through sieve of 32,257 meshes per square inch.	10·2 per cent. left on sieve of 2,580 meshes per square inch.	All passed through sieve of 32,257 meshes per square inch.	10·2 per cent. left on sieve of 2,580 meshes per square inch.	All passed through sieve of 32,257 meshes per square inch.
Weeks.	Lbs. per square inch.	Lbs. per square inch.	Lbs. per square inch.	Lbs. per square inch.	Lbs. per square inch.	Lbs. per square inch.
1	353	346	75	252	31	136
4	533	380	171	330	97	208
8	585	469	206	358	118	223
25	710	495	282	397	166	272

The specification for the works of the Forth Bridge required that the cement should pass a sieve containing 50 divisions to the inch, equal to 2,500 meshes per square inch, leaving a residue of not more than 5 per cent. by weight. For the tests it was mixed with three times its weight of sand, which had been passed through a sieve of 400 meshes (20 divisions per lineal inch) and retained upon one of 900 meshes to the square inch (30 divisions per lineal inch).

About 10 per cent. of water was used in making the mortar. The briquettes were immersed in water after twenty-four hours, and so remained twenty-five days, when they were required to bear a strain of not less than 170 lbs. per square inch without breaking. For briquettes of neat cement the breaking stress after four days was not to be less than 200 lbs., and after seven days not less than 400 lbs. per square inch.

The class of sand selected will influence the strength of a structure very considerably, and may require more or less cement according to its quality. Pit sand has an angular grain and a porous, rough surface; it is therefore good for mortar. River sand is not so sharp, the grains having been polished by attrition, whilst sea sand is deficient from the same cause. Where great fineness is required, it should be ground and passed through a sieve. Clean sand should leave no stain when rubbed between the hands, but a sand so clean is rarely met with in up-country districts; washing will therefore be required in almost all cases, as the presence of clay and loam unfits it for all purposes. This can be readily done by stirring in a wooden trough having a current of water flowing through it.

Calcareous sands give stronger mortars than siliceous ones; sea sand, by containing salt, is apt to attract moisture, which can be largely obviated by washing in fresh water.

The water required to slake hydraulic limes or for the mixing of cement mortars varies very much, and is influenced by the district in which the works may be situated; in hot climates a large increase of water

will be used. Hydraulic limes should be left after being wetted and covered up for a period of from twelve to forty-eight hours; the greater the hydraulic properties they possess the longer they will be in slaking; too much water will absorb the heat and check the slaking process. Strong hydraulic limes should be ground before using. The quantity of water required for mixing mortars will vary between 7 to 20 per cent. of the bulk of the ingredients; too much water must on no account be used.

In mixing the great object to be attained is to thoroughly incorporate the ingredients, so that no two grains of sand shall lay together without an intervening film of cement. On all works of over an estimated cost of £5,000 mortar mills should be adopted; this is absolutely necessary for the intimate incorporation of large quantities. The cement and sand should be mixed dry, the ingredients being turned over two or three times before the water is added; a very thorough incorporation of the materials is effected in this manner.

The bulk of mortar produced from various mixtures varies according to the size of the sand used. For estimating the quantities required, however, in a structure, three-quarters of the bulk of the cement *plus* the bulk of the sand in mixtures of 1 to 2 of sand to 1 to 4 of sand will be a near approximation to the total bulk obtained for building (see also page 77).

The artificial compound known as concrete is made by mixing lime or cement and sand with water and adding some hard material, such as broken stone,

clay, gravel, &c. The broken material is generally called the aggregate, and the mortar which incases it the matrix. Aggregates composed of angular fragments rather than rounded pieces (such as are obtained from gravel) are to be preferred, their size not being greater than will pass a ring of $2\frac{1}{2}$ inches diameter and not less than $1\frac{1}{2}$ inch. The sand and cement will be dry mixed by being turned over two or three times before applying the water. When the mortar is made it can be added to the aggregate, which has also been carefully gauged and wetted, so that the stones will not suck the moisture out of the matrix. The whole, on being turned over three or four times, will form a thoroughly incorporated concrete.

A very strong and impermeable concrete can be made by a mixture of 1 of cement to 2 of sand and 3 of broken stone, the sand and cement together being sufficient to more than fill the voids or interstices of the aggregate. By the former rule one cubic yard or 27 cubic feet of cement plus 54 cubic feet of sand would, when mixed, equal 60·75 cubic feet of mortar. Now experiment has demonstrated that a mixture of 1 part of cement to 2 of sand and 3 of sharp broken stone will equal about 0·60 of the total bulk when thoroughly incorporated. We have therefore $27 + 54 + 81 = 162 \times 0{\cdot}60 = 97{\cdot}2$ cubic feet, which is greater than the cube of the aggregate by 16·2 cubic feet. There is that amount, therefore, more than is required to fill the voids in the aggregate. Care and attention should be paid to these details, or a very faulty concrete may be the result, the blame of which

cannot rest with the contractor, but must be borne by the engineer. (See remarks upon porosity.)

The amount of water required for mixing will vary between 10 and 25 per cent. of the total bulk of the ingredients, according as the temperature of the air is high, or low, or moist.

One precaution that must be taken is that an absolutely clean water supply be obtained for the mixing of the mortar and concrete. To thoroughly wash the sand and stone used, so as to remove clayey particles, and afterwards to use dirty water, is equivalent to not taking any precautions whatever; only a small proportion of clay in the sand or mortar will literally kill out the adhesive qualities of the cement.

The concrete when made should be wheeled rapidly to the place where it is required and gently tipped into position, being rammed in layers of twelve inches thickness; the layers should be horizontal, so that there may be no trickling of water, which would carry cement with it. Where surfaces are left by any interruption or for convenience of work such surfaces, before laying more concrete on them, should be swept clean, made rough by a hand pick, washed, and covered by a thin coating of cement. Generally a thin milky exudation will be observed upon the surface of the concrete last laid if a few days have passed. This must be removed, as it will prevent the next layer from adhering. A slow-setting cement is preferable to that which sets quickly, cracks being very liable to appear after too rapid a setting. When set the surface must be kept drenched with water, so that

the atmosphere may have no deleterious influence before further building operations are begun upon it.

We have seen that the fineness of cement increases the tensile strength of mortar; it has also a direct bearing upon the water-tightness of both mortars and concretes. This is a very important constructional matter in masonry dams, and merits attention. We have already noticed that mixtures of 1 of slaked lime or cement to 2 of sand, or 1 to 3 or 1 to 4 in volume, give about 75 per cent. of their total volume when mixed. This is, however, but a rough average and indication of the water-tightness of the cement mortar. As it is evident that 1 to 2 will give, by this calculation, 2·25, and therefore contains an excess of cement, 1 to 3 will give 3, the voids being just filled, whilst 1 to 4 gives 3·75, or 0·25 less than the original sand, showing that there are still voids to be filled. By mixing 1·32 in volume of cement to 4 of sand we have the original 4 of sand with the interstices filled.

Investigations made by the author in a series of experiments have led to the following facts being disclosed. An up-country sand obtained from rivers, when sifted through a sieve with one-eighth inch square holes, and afterwards washed, will contract when thoroughly saturated with water, as it will be in mixing, 23·3 per cent., and the voids remaining are equal to 32 per cent.—that is to say, that wet sand, as taken from the washing boxes or troughs and placed in the gauge box, will afterwards shrink, when mixed by the action of water and movement,

23·3 per cent., there still remaining 32 per cent. of voids to be filled with the cement. This affects, it will be seen, very considerably the calculated quantity of sand required in works of large dimensions, as the total washed sand will only equal, when used in the building, 76·7 per cent. of the gauged quantity.

We should have, therefore, in a mixture of 1 of cement to 2 of sand by gauge, 68 per cent. of the total volume as mortar; in 1 to 3, 64 per cent.; and in 1 to 4, 62 per cent. of the total as mortar. Now water-tightness is obtained by filling the voids in the sand, and as the sand, when thoroughly saturated with water, as occurs in making the mortar, contains 32 per cent. of voids, it is easy to see that 1 of cement to 3 of sand is about the limit of sand that can be given if water-tightness be required, there still being a slight excess of cement over and above the voids contained in the sand. As the sand, however, when gauged, will shrink in mixing 23·3 per cent., we have for the original 3 only 2·30 in volume of sand, which, containing 32 per cent. of interstices, results in 1·56 of solid sand, which, when mixed with 1 of cement, equals 2·56 of mortar. It will also be seen that when the 1 of cement is added to the 2·30 actual of sand the voids are more than filled, as 2·56 results in volume, or 0·26 more of cement than is required to fill the interstices. This excess is required for the adhesive films between the building stones and the mortar. By calculation, then, we are assured that the construction, when built of this mixture, will be water-tight.

As a demonstration that the above fulfilled all requirements, a masonry dam was constructed in the Province of Huelva, Spain, under these conditions, the mortar being composed of 1 of cement to 3 of sand. A little more than one-third of the whole structure was mortar, the remaining two-thirds being stone; the dam having a maximum height of 70 feet. The mortar was exposed to a water pressure at the base of 30 lbs. per square inch, which it resisted, the down stream face being perfectly water-tight after sweating slightly for the first few months.

A water-tight concrete can be made by mixing 1 of cement to 2 of sand with 3 of broken stone not larger than $2\frac{1}{2}$ inch cube or less than $1\frac{1}{2}$ inch cube. Here it is seen that the sand becomes 1·53 with 32 per cent. of voids, or 1·04 of sand to 1 of cement, the mixture being 2·04, or 0·51 excess of cement over and above the voids of the sand. The 3 of broken stone with the 2 of sand and 1 of cement will equal, when mixed, 60 per cent. of the total volume, or 3·6. The voids in the broken stone are therefore 52 per cent., and, as 52 per cent. of 3 equals 1·56, the 2·04 of sand and cement are more than sufficient to fill the voids by 0·48. There is consequently ample cement in this mixture to insure water-tightness.

The above figures are obtained, as before stated, with sand that was riddled with a one-eighth inch square hole sieve, and will, of course, vary with the quality of the sand used. The cement was finely ground, 90 lbs. per cubic foot being obtained with difficulty, owing to its fineness. Eighty-five pounds per cubic foot

in a mixture of 1 to 3 of sand would hardly be sufficient with the above class of sand to fully occupy the interstices; porosity would therefore not be overcome. For the purposes of estimating costs and demonstrating water tightness they may with safety be adopted.

It will be observed that the volume of cement in the above mixtures is accepted as such without any allowance for shrinkage. Ninety pounds per cubic foot of finely ground cement contains about 50 per cent. of voids; the actual cube is consequently only half, but the addition of the water for mixing and the pores left in the mortar when mixed and set make up the difference to within a very small percentage. For simplification of calculation and deduction the cement has been retained as a full volume in all cases. A hand-made mortar will always contain a few air holes or voids when set unless very well mixed. A 1 to 3 mortar when set, if broken across and examined under a magnifying glass, will be found to contain more open spaces or voids than a 1 to 2 mortar when examined in the same way, the few pores observable being partially attributable to air in the mixture. Well made machine mortar and concrete is very free of air holes or voids when subjected to the same examination.

The mortar used in the construction of the Vyrnwy Dam, for the supply of water to Liverpool, was 1 part of cement to 2 parts of sand. Experiments were made as the work progressed, and it was found that by pulverising the stone—a grey slate rock, of which the dam was built—and mixing 2 parts of this with 1 of the sand, and using 2 parts of this mixture with

one of Portland cement, a stronger mortar resulted, and this mixture was ultimately adopted.

The Geelong Dam, Victoria, Australia, was built entirely of concrete, being 60 feet deep. It was subjected to a maximum water pressure of 26 lbs. per square inch. The best results were obtained by mixing the ingredients in the following proportions :—

2-inch stone	....	$4\frac{1}{2}$ parts.
Screenings	....	$1\frac{1}{2}$,,
Sand	....	$1\frac{1}{2}$,,
Cement	....	1 ,,
Total	....	$8\frac{1}{2}$ parts.

In this case the 2-inch stone and screenings when mixed could not have contained more than 30 per cent. of voids, as the $1\frac{1}{2}$ of sand and the 1 of cement would not give much more than 1·78 of mortar, and in this way about 70 per cent. of the original cube would be obtained for building. There is certainly no excess of cement in this mixture. The average weight of the concrete was 143 lbs. per cubic foot.

When the reservoir was filled a little water found its way through the dam, but this leakage soon stopped, owing to hard incrustations of lime being formed.

The Tytam Dam, near Hong Kong, was built with three classes of concrete and ashlar facing of granite; behind the ashlar masonry there is two feet of fine concrete, composed of 4 parts of stone (1-inch cubes), 6 parts of sand, and $2\frac{1}{2}$ parts of Portland cement, which is 5·63 parts of mortar to 2·08 of voids in the stone, giving a great excess of mortar. This formed a water-

tight skin. Next came five feet of concrete, composed of $4\frac{1}{2}$ parts of stone, $3\frac{1}{2}$ parts of sand, and 1 of cement, the hearting consisting of the last class of concrete with stones of 3 to 6 feet in size embedded in it. These stones were kept well apart, so as to allow the concrete to be well rammed between them. The ashlar masonry was grouted with mortar composed of 1 of cement to 2 of sand.

The height of this dam is 95 feet; the maximum pressure of water is therefore 41 lbs. per square inch. Any water that might leak into the wall was allowed to escape through perforated zinc pipes $1\frac{1}{2}$ inch diameter, which were placed 5 feet apart. When the water had risen 45 feet the leakage could be carried off by a 1-inch pipe without pressure; it was therefore very slight with that depth of water.

Mr. J. Watt Sandeman, in an excellent and useful paper contributed to the Min. Inst. C.E., vol. cxxi., on Portland cement and concretes, gives the ratio of interstices of different aggregates as follows :—

	Weight of aggregates per cubic foot.	Ratio of interstices.
	Lbs.	Per cent.
Broken limestone, the greater part of which would be gauged by a 3-inch ring	95	50·9
Gravel, screened free from sand, varying in size between small pebbles and pieces gauged by a $2\frac{1}{2}$-inch ring	$111\frac{1}{2}$	33·6
The above limestone and gravel well mixed in equal proportions	$113\frac{1}{2}$	33·6
Sandstone, varying in size between pieces gauged by a 4-inch ring and pieces gauged by an 8-inch ring	74	50·0
Sandstone, varying in size between sand and pieces gauged by a 4-inch ring	92	34·0
The two above sandstones mixed in equal proportions	$91\frac{1}{4}$	36·0

And he further remarks, on the manipulation of concretes, that, from studying the facts adduced in regard to the greater strength and economy attained by duly proportioning the components of concrete, he strongly deprecates the slovenly and unscientific practice of using in the manufacture of concrete unscreened gravel and sand, as although in cases where such material is employed the approximate ratio of sand to gravel is sometimes supposed to be ascertained by sifting a few samples, yet this ratio varies so widely—viz., between 19·5 per cent. and 113·6 per cent., according to the tests of Mr. Colson—that it would be quite impossible to obtain uniformity. Moreover, as the ratio of sand to gravel in the most economical concretes has been shown to range between 28½ per cent. and 45 per cent., it is clear that the varying natural ratio of sand to gravel would not make economical concrete, as, even assuming that the ratio of sand in any gravel were exactly according to requirements, it would be immediately altered by casting the material into waggons or barges. Again, by tipping them into a heap the sand and gravel always separate and assort themselves under the influence of gravity, and the author has witnessed the practical impossibility of combining the two again in due proportions when shovelling them out of a heap. Where concrete is made from unscreened gravel there must of necessity be portions of it in which the interstices of the gravel are not filled, and others in which the mortar is in excess, and in consequence the strength of such concrete is very variable. It would also be

quite impossible with unscreened materials to make water-tight concrete, except by using an unnecessary excess of cement, entailing a proportionately increased cost.

In hand-mixed concrete the quantity of water necessary to render one mixing of the proper consistency having been noted, the same quantity of water should be used for each mixing, the uniform consistency of the concrete being of vital importance. The thorough hydration of the cement is also of paramount importance; but, as the quantity of water required will vary with the age and quality of cement, the character of the sand and the aggregates, and the state of the weather, the proper quantity to insure thorough hydration, without washing the cement out of the concrete, or causing the aggregates to settle down in contact with each other, can only be determined by the observation of an engineer experienced in the manufacture of concrete.

It may be stated as a guide that, when deposited *in situ*, the concrete should be somewhat of the consistency of dough, and should always yield sufficiently to allow of a man treading it to sink in it to a depth of at least six inches. Workmen should always be employed to tread and shovel each mixing of concrete throughout while it is being deposited; otherwise water-tightness will not be attained. In order to insure this engineers should require contractors to provide men treading the concrete with waterproof boots.

Concrete mixing should not be allowed to proceed during very windy or wet weather, unless performed

under efficient shelter, as a considerable percentage of the finest and most valuable part of the cement will be blown away, and during rain the cement and sand cannot be efficiently mixed.

The concrete should in all cases be deposited in such a manner as not to allow the aggregate to separate from the mortar under the influence of gravity. To lessen this risk the size of the largest aggregate should be limited to such as would pass through a sieve with meshes two inches square. Further, to prevent the separation of aggregates, concrete should never be passed down a shoot; and, if tipped from a height, a layer of two to three feet in depth should first be deposited by lowering it in tubs. For large works regularity in mixing concrete may be attained by the use of a mechanical mixer, provided it be an efficient one, as there are so-called mixers worse than useless by causing the separation of the aggregates from the mortars. The chief advantage of a good machine is the facility which it affords for making concrete with a uniform quantity of water and of uniform consistency, which cannot be easily attained by hand-mixing.

Having noted the essential points as regards the stone, mortar, and concrete, we now come to another important part of the construction—that is, the proportion of mortar to stone in the whole structure. A heap of tipped building stone, without waste, will have about 50 to 52 per cent. of voids, whilst the selected stone and its waste, or the whole of the material won by the quarrying operation, if tipped apart, will augment in volume about 33 per cent. These figures

are mentioned as showing that not more than one-third of the whole structure should be mortar, as otherwise the masons are not obtaining less voids around the stones than would be given by tipping the stones roughly on the ground. By laying the stones carelessly, therefore, an excess of mortar would be required, which would not only expose the structure to additional sweating, but increase the cost very considerably. If any leakage result it will be through the mortar or joints rather than through the stone. The stones must not only be carefully laid, but a large quantity of spalls should be driven in to fill all corners, points, and voids in and around the building stones; and there is no doubt that with skilled labour 0·75 in volume of mortar to 2·25 of stone can be attained in rubble masonry. But generally these structures are built up-country, and far removed from the probability of obtaining skilled labour; 1 of mortar to 2 of stone is therefore nearer what will be obtained in practice under skilled supervision.

It is generally thought that in the thorough setting and ageing of the mortar, in masonry walls of such thicknesses as are required to resist the pressure of water in even moderately high dams, they become a perfectly solid and immovable block, but such is not the case. This points, therefore, to the necessity of most careful supervision during construction; otherwise the calculations applied to the form of the adopted profile will be erroneous, the least amount of masonry being used that will bring the lines of resistance within the middle third of the profile. This, although leaving a

margin of safety, nevertheless requires the dam to be well built. The Vyrnwy Dam has a bore-hole connecting the sill to a gallery running longitudinally through it rather more than 80 feet in depth ; in the bore-hole is suspended a steel pianoforte wire carrying at its lower end a heavy weight immersed in water ; near the bottom of the wire is a seismograph, the movements of which are multiplied four times. The first observations were made when the water in the reservoir was within 13 feet of the sill, or top of the dam ; during this 13 feet rise of water the sill moved horizontally, in relation to a point 80 feet below, to the extent of 0·868th of a millimetre. The changes of temperature caused the dam to move sensibly from day to night and from night to day, whilst earth tremors were clearly recorded. The dam faces south-east, so that it does not receive the full heat of the sun ; but when the reservoir is full the difference between a hot summer day and night was 0·366th of a millimetre, due to the expansion of the outer face of the wall.

We have here the first and only recorded movements of a dam from the above various causes—which took place, it must be remembered, in a wall that was increased considerably in width over and above the required calculated profile from about one-third of its height from the top to its base, as the whole crest or top of the wall was utilized as a weir over which the surplus water from storms, &c., might pass.

It is therefore evident that too much care and supervision cannot be bestowed upon the workmanship and materials in the construction of high dams.

LEAKAGE AND SWEATING.

However carefully a dam may be built there will always be a certain amount of leakage, which should not amount to more than sweating on the down stream face when the reservoir is first filled. This loss of water in well built dams disappears after a few months. What is more serious, and will give cause for grave anxiety and trouble, is the appearance of leakage from the base and foundations of the wall. This, if not great, will also seal in course of time, but it is certainly advisable to make careful observations as to the volume given and its variation with the level of the water in the reservoir during a period of several months. If the leakage be permanent, the volume will vary in proportion to the square root of the head of water in the reservoir.

Such a leakage involves sometimes an immense amount of costly work, and generally necessitates the emptying of the reservoir before anything effectual can be done. If the leakage be suspected to be at the lowest point, or near the lowest point, of the dam, the basin of the reservoir that is in close proximity to the wall may be covered with a well prepared clay, which can be tipped into the water and allowed to settle by its own gravity round and about the inner base of the wall, the pressure of the water tending to drive the clay into

the false joints or vein. This operation is necessarily done with the level of the water lowered to a convenient depth. The water for a short period will be made turbid from a small portion of the clay being in suspension, but this will soon fall, and the water will again become clear. A little alum thrown in will clear the water very quickly, and may with advantage be employed in case of urgency.

The above procedure is applicable in cases of dams of considerable height in closed valleys or gorges, where the inner toe can be easily protected and covered. An extensive and shallow basin would necessitate other methods being adopted, such as a trench being cut in the solid rock along the inner toe of the wall, to be afterwards filled with puddled clay or cement concrete, in either case being connected to the wall on the inner face in such a way that the wall and the material of the trench form a complete union. This will form an apron, and most effectually cut off any possible leakage, but is an expensive and tedious operation.

Another danger, already mentioned, to which a wall is exposed, particularly along its top, is that of expansion and contraction, and although this is allowed for by the formula for the profile, still the greater the length of the top the greater the danger becomes of vertical cracks appearing in the course of time, particularly if during the heat of a dry season the reservoir be only partially filled. The top will, in this case, be exposed to considerable variation, and possibly result in a few cracks of slight thickness appearing, but nevertheless of sufficient size as to permit a consider-

able quantity of water to pour through the wall. Between the heat of summer and the cold of the winter months the top of a wall will be exposed to a variation in length equal to about one inch on every 350 feet length when built of rubble masonry or concrete. The interior of the masonry of a wall is not exposed to the same variation as the exterior, but nevertheless the influence is greater than might be expected, as demonstrated by an experiment made in America, where the range of temperature in a wall of five feet six inches was, during twelve months, as registered by a maximum and minimum thermometer, about 20°. The face of a dam may, from the same cause, be cracked in many directions, an instance of which is the concrete reservoir wall at Colombo, which is fissured in all directions, and is now shielded from the sun's rays by an earthwork slope.

Vertical fissures appearing through a wall do not necessarily endanger the structure when caused by contraction, and they may be readily calked by oakum derived from old ropes. This will be slightly elastic, and for some few years yield with the movement of the wall. Grouting should not be employed on any consideration, neither is pointing on the inner face effective or desirable.

As appertaining to the question of leakage of masonry dams, the following interesting pages are appended, relating to the investigation of the causes of failure of the Bouzey Dam, in France.

FAILURE OF THE BOUZEY DAM.

The Bouzey Dam is situated about $4\frac{1}{2}$ miles from the town of Épinal (Vosges); its general dimensions are—

Length on top	....	1,700 feet.
Height above river bed	....	49 ,,
,, ,, foundations	....	$75\frac{1}{2}$,,
Width at top	....	13 ,,
,, ,, base	....	39 ,,

The plan of the wall is straight. The profile was designed to be one of "equal resistance," each joint being assumed perpendicular to the resultant of all the forces acting on it. When the reservoir is full there is tension in the masonry near the back face.

The dam was founded on a porous conglomerate rock consisting of silicious stones joined together with a rather weak cementing material. Specimens of this rock resisted a crushing load of 274–548 tons per square foot, but broke under a tensile strain of only 10·10 tons per square foot.

In the Minutes of the Proceedings of the Institute of Civil Engineers, vol. cxxv., 1895–96, Pt. 3, page 461, an abstract is given from the report of a special commission of the Ponts et Chaussées upon the failure of this dam, from which the following is taken, as the investigation made and conclusions formed are of

great practical importance to all designers of masonry dams:—

"Mr. Delocre assumes in his calculations, taking a unit length of the dam, that, in any horizontal section, the thrust due to the horizontal pressure of the water above that level is counteracted by the friction and cohesion of the mortar in that plane, and that the section has to support a vertical pressure equal to the weight of the portion of the dam above that level applied at the point where the resultant of that weight and the water pressure intersects the plane. The intensities of the pressures are calculated on the assumption that the stress varies uniformly across the section. The profiles of the Furens Dam (164 feet high) were calculated according to this method, the maximum vertical pressure being limited to 5·9 tons per square foot; likewise those of the Ban Dam (148 feet high), but in this case the limiting pressure was increased to 7·3 tons per square foot. In the Tournay Dam (116 feet high) the limit was taken as 6·4 tons per square foot.

"After the completion of the last-mentioned dam it was decided to raise it 3·3 feet, and Mr. Bouvier, in recalculating the stresses, introduced a modification into the method adopted by Mr. Delocre, by which the maximum pressures arrived at by the first system are divided by the cosine squared of the angle which the resultant makes with the vertical to get the true maximum. This gave the maximum pressures in the Tournay Dam as 8·5 tons per square foot instead of 6·4 tons per square foot by the first method; and he

introduced that, taking account of this correction, a dam built of good hydraulic lime might be subjected to a maximum pressure of 9·0 tons per square foot after two or three years and 12·8 tons per square foot after twelve years.

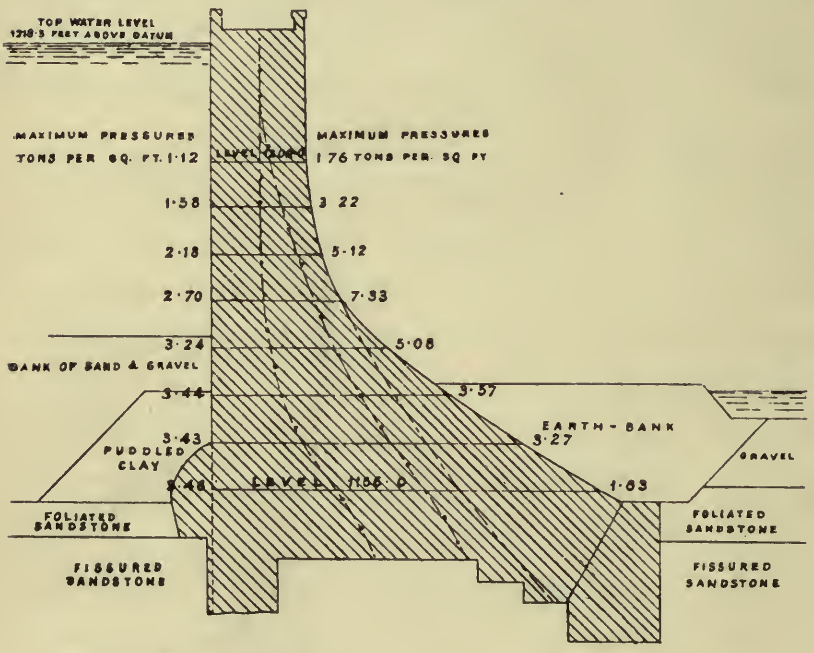
"Mr. Guillemain, while adhering to Mr. Bouvier's method, advocates that the pressure should be calculated on all planes passing through the point sustaining the maximum pressure, so as to arrive at the actual maximum pressure in a dam.

"The effect of a dam being waterlogged below a certain level for a given distance from the face is next considered, and is shown to decrease the amount of the resultant and to move its point of application nearer to the outside face.

"The figure (Fig. G, p. 94) shows the section adopted for the dam in dotted lines; it was approved of by the Council of the Ponts et Chaussées on the understanding that the dam should not be raised at once to its full height, but that the level of the water should be kept provisionally at 1,212·0 feet above datum, and not be raised to its ultimate level, 1,218·5 feet, until the dam had thoroughly consolidated. The lowest draw off was fixed at 1,169·3 feet. The dam was straight, and its length was 1,700 feet; the contents of the reservoir at the provisional level being 1,034 million gallons, and at the final level 1,540 million gallons. The dam was built on the new red sandstone, which was fissured and permeable, and to prevent the water getting underneath the dam a guard wall was carried down beneath the water face into the

solid rock. The masonry was built with hydraulic lime mortar, and the inner face coated with plaster of cement mortar 1½ inch thick.

"The guard wall was built in 1878 and 1879, and in its construction springs were met with that were with difficulty sealed. The dam itself was built up



Section First adopted ----------

Lines of resultant pressures for amended section, reservoir empty & full. —·—·—·—

FIG. G.

to the level of 1,187 feet for a length of 820 feet in 1879, and completed in 1880. During its construction the engineers, on representing to the Minister of Public Works the greatly increased storage that would be obtained at a small additional cost by at once raising its height to the ultimate level, obtained permission to do so.

"The filling of the reservoir was started in November,

1881, about a year after the completion of the masonry, with the water of the river Avières. When the water in the reservoir attained the level 1,187 feet springs appeared on the lower side of the dam having a flow of about two cubic feet per second. In December, 1882, two fissures, at distances of 243 yards and 332 yards respectively from the overflow, were noticed in the dam, and supposed to be due to changes in temperature, as they were also apparent during the preceding winter. These caused the discharge of the springs to increase to 2·6 cubic feet per second. By the 4th December, 1883, the reservoir had only been filled up to a level of 1,197 feet, but after that date the filling proceeded at a greater rate, owing to the utilization of the waters of the river Moselle.

"On the 14th March, 1884, when the level of the water in the reservoir was 1,210 feet, a length of 444 feet of the dam suddenly assumed a bent form between the points 119 yards and 267 yards, and the flow of the springs increased from 2·6 cubic feet per second to 8·1 cubic feet per second. The height of the water in the reservoir was kept constant for a year after this. No further movement took place, and the flow of the springs remained nearly the same.

"In 1885 a bore-hole was put down on the lower side of the dam, and afterwards the reservoir was emptied to ascertain what had actually happened. It was found that the dam had separated from the masonry wall beneath it between the points 148 yards and 247 yards, still keeping the vertical, the greatest deviation from the straight being 1·1 foot

at the centre of deflection. On the inner face, at each end of the displaced length, was a group of fissures. That on the right on the inside, only visible on that face, consisted of three cracks at the points 117 yards, 123 yards, and 130 yards from the overflow respectively, descending obliquely to the base of the dam, the last one joining the horizontal cracks by a ramification. On the left were four cracks visible on the inside face—the temperature crack at 243 yards, which went vertically through the dam to the outside face, as also did the crack at 267 yards. The crack at 256 yards was vertical, but visible only on the inner face, and finally a fissure, inclined at about 45°, at 267 yards, which cut at its base the fissure at 256 and joined the horizontal fracture. The cracks at the centre of the deflection were visible on the outer face.

"The formation beneath the displaced part of the dam was dislocated for two or three yards in depth, and two crevices were noticed from which springs issued, also deposits of clay, in lenticular beds, which usually were less than one-tenth inch in thickness; above the dam fissured and permeable beds were found which passed beneath the foundations of the guard wall.

"Following the recommendations of a special commission of the Ponts et Chaussées, it was resolved to form an abutment of masonry on to the solid rock at the outer toe of the dam, starting at the level 1,182·4 feet, drains being laid through the masonry to lead away any water percolating underneath the dam. A wall of masonry was to be built on the

water side at the junction of the guard wall and the masonry of the dam proper, and covered with puddled clay to a depth of about three yards. Wherever the cement plastering had become detached the joints were to be raked out and filled with cement mortar. The fissures also were to be filled with cement mortar, or cement grout when difficult of access.

"The tubes lining the boring on the lower side of the dam were carried up above ground level, so that as the water rose in the reservoir its height in this tube could be gauged.

"These works of repair were executed in 1888 and 1889, being complete on September the 14th, 1889; the figure gives the amended section in full lines. The filling of the reservoir was recommenced on the 18th of November, 1889.

"The flow of the springs increased from 0·5 cubic feet per second, to start with, to 2·8 cubic feet per second on the 15th of May, 1890, when the level of the water in the reservoir was 1,218·5 feet above datum, that in the tube lining the bore-hole being 38·4 feet lower. The level of the water in the tube followed that in the reservoir as the latter filled.

"The deflection of the two points distance 193 yards and 267 yards from the overflow, the middle and one end of the portion displaced in 1884, was read by means of a theodolite.

"The reservoir began to be used for feeding the Canal de l'Est on 15th May, 1890. The level of the water was raised each year to 1,218·5 feet, and was never

lower than 1,210·6 feet. The flow of the springs varied from 1·4 cubic foot per second to 2·6 cubic feet per second. The maximum level of the water in the tube was 1,184·4 feet, and it was never lower than 1,179·5 feet.

"The point at 193 yards deflected 0·32 inch to 0·72 inch, and the point at 267 yards from 0·04 inch to 0·25 inch. The vertical fissures opened in the winter and closed in the summer, attaining a maximum width of 0·28 inch. On April 27, 1895, at a quarter to six o'clock a.m., when the level of the water in the reservoir was 1,218·2 feet, a length of 594 feet of the central part of the dam was suddenly overturned at the level 1,186 feet, between the points at the distances 149 yards and 347 yards respectively. This length includes all but 90 feet of the part that was displaced in 1884. The fracture was nearly level longitudinally, and transversely it was level for 12 feet and then dipped towards the outside. The foundations had not moved, and the masonry was found to be of good quality.

"The commission appointed to inquire into the cause of the disaster calculated, according to Mr. Bouvier's formulas, the maximum intensities of pressure in the dam for the provisional and ultimate height of the water in the reservoir, and for an additional elevation in its level of 1·6 foot to allow for the highest possible overflow level; and the results are given in the accompanying diagram for the ultimate height of the water. The weight of the masonry was taken at 125 lbs. per cubic foot. With the ultimate height

of the water at the level 1,182·4 feet, this method of calculation gave a maximum intensity of pressure of 7·3 tons per square foot and a ratio of water pressure to weight of masonry above that point of 0·695; with the extra elevation of 1·6 foot, a maximum pressure of 10·6 tons per square foot and the above ratio of 0·736.

"Mr. Bouvier gives the maximum intensity of pressure in five dams as follows:—

Name.	Date of construction.	Height of water in reservoir.	Maximum stress in masonry.
		Feet.	Tons per square feet.
Gouffre d'Enfer	1861—1868	164	8·6
Tournay, before rising	1861—1867	116	8·5
,, after rising 3·3 feet ...	1861—1867	119	11·0
Ban	1866—1870	148	10·0
Pas de Riot...	1833—1878	110	9·1
Chartrain	1888—1893	151	9·4

"Thus the maximum pressure in the amended dam at the level of 1,182·4 feet, calculated in this manner, was less than in the above five dams. But an examination of the diagram showed that the resultant fell outside the middle third of the section. Therefore, if the dam below this level (the point at which strengthening began) was considered as fixed, and the stresses worked out in the usual way for the joint at the level of 1,182·4 feet, the maximum vertical pressure thus found was 4·6 tons per square foot, and the maximum tension 1·3 tons per square foot; and, for the joint 3·3 feet above, the maximum pressure and tension were respectively 4·3 tons per square foot and 1·0 ton per square foot.

"The cracks in the dam had not been properly filled

with cement grout, as had been proposed, because they were for the most part very narrow and would not take it, but they had been closed on the face by means of tarred yarn fixed with wooden wedges. This left the interior of the fissures still open. The vertical fissures were not harmful, but the one at 267 yards communicated with the oblique crack, and a dangerous uplift was caused at that point. If the fissure had a depth of five feet the maximum pressure in that section would be 18·1 tons per square foot; if it had a depth of ten feet the resultant pressure would be outside the dam at this section. It thus appeared that the oblique fissure at 267 yards could determine the rupture of the dam for some yards in length, unless the support this portion received from the adjoining parts kept it in position. The results stated above showed that the remainder of the dam was in a state of tension on the inside face at the joint at a level of 1,182·4 feet and for some distance above. In the first season's work the dam was built up to the level of 1,187·0 feet, and about 18 inches was taken down on restarting work the next season; consequently a weak place at the junction of the two seasons' work occurred at the same section in which tension existed. It appeared that the dam gave way at the oblique fissure first, and brought the remainder of the 594 feet, which was in a state of excessive strain, with it. This coincided with the evidence of the only eye-witness and with the state of the dam after the accident.

"The commission agreed that if the provisional level for which the dam was approved had been adhered to

no serious accident would have happened, as in that case there would have been no tension. The following are the conclusions of the commission :—

"1. The masonry of the Bouzey Dam was exposed to tensions which exceeded its powers of resistance on account of the defective adhesion of the part built in 1880 to that built in 1879.

"2. The catastrophe of Bouzey shows that it is necessary to so design reservoir dams that the masonry is not exposed to any tension.

"3. In case of such accidents as that at Bouzey in 1884 there should be no hesitation in rebuilding entirely all portions of the masonry in which there are fissures which might give rise to uplift.

"4. The conditions of stability of existing dams should be inquired into, and, if necessary, the level of the water reduced so as to do away with all tension in the masonry."*

* The failure of this dam is often referred to by engineers, and a considerable amount of thought and labour has been given to demonstrating the reason of its failure, without indicating, however, the reason of its having stood so long, which was indeed astonishing considering its profile.—C. F. C.

PRECAUTIONS AGAINST EARTHQUAKES.

EARTH tremors and quakes are likely to produce disastrous effects on masonry dams in which there is no elasticity. Earthen dams, on the other hand, particularly if not of great height, will resist very considerable movement of the earth without damage; the lashing backwards and forwards of the water of the reservoir being the greatest danger from which they are likely to suffer.

Professor John Milne, in an appendix upon this subject written for Mr. W. K. Burton's work on the "Water Supply of Towns," says :—"That great advantage can be gained by selecting a proper site in earthquake countries is indicated by the fact that in building regulations for districts where earthquakes are frequent—as for example in Manilla and Ischia—special references are made to the methods of founding on soft ground, and in many cases certain areas have been marked off as unsuitable for buildings of any description."

He further states "that in making dams for impounding reservoirs it must not be forgotten that these may be subjected to a horizontal shaking, with the result, if they are made of loose material, that this may be disintegrated much in the same way as a pile of

sand would be on a shaking table. For this reason it is better in earthquake countries to follow the English rather than the American practice in designing dams for impounding reservoirs.

"In connection with these dams it must be remembered that they may possibly be topped by waves caused by the earthquake motion. This is a strong argument for the adoption of a dwarf wall as a 'breakwater' along the top of an earthwork dam in an earthquake country. It might be further advisable to pitch with stones the top and lower slope of the dam, as well as the upper slope, so that if it were merely a case of topping with a few waves in succession there would not be the danger of cutting away the earthwork that there would be without the pitching."

It is impossible to give any rule which might be followed with safety, but one can only point out that large impounding reservoirs found in earthquake countries are a source of constant danger to any town or village that may be situated below, and in the direction which the freed water would take if a rupture were caused by earth tremors. A series of small dams, on the other hand, would resist very effectively any moderate quake of such force as would completely destroy an embankment or wall of great height.

APPENDIX I.

APPENDIX II.

APPENDIX III.

APPENDIX I.

Estimate of Cost for Masonry Dam 100 feet in height, showing Subdivision of the Materials.

18,000 cubic yards of masonry	=	12,000 cubic yards of stone. 6,000 cubic yards of mortar.
6,000 cubic yards of mortar	=	2,344 cubic yards of cement. 7,031 cubic yards of sand.
2,340 cubic yards of concrete = 3,900 cubic yards of aggregate and cement =		650 cubic yards of cement. 1,300 cubic yards of sand. 1,950 cubic yards of stone.

The above concrete and mortar can be further subdivided to obtain the cost per cubic yard for each class.

Mortar :

	£	s.	d.
1 cubic yard of cement at 90 lbs. per cubic foot = 2,430 lbs. at 40/- per ton =	2	3	5
3 cubic yards of washed sand at 4/- = ...	0	12	0
4 cubic yards × 0·64 = 2·56 cubic yards =	£2	15	5
or 21/8 per cubic yard ; therefore			
1 cubic yard of mortar = ...	1	1	8
Mixing and carrying to site = ...	0	2	0
Water pipes, &c. = ...	0	0	4
Total per cubic yard	£1	4	0

Concrete:

	£	s.	d.
1 cubic yard of cement at 90 lbs. per cubic foot = 2,430 lbs. at 40/- per ton =	2	3	5
2 cubic yards of washed sand at 4/- = ...	0	8	0
3 cubic yards of broken stone at 2/6 = ...	0	7	6
6 cubic yards × 0·6 = 3·6 cubic yards =	£2	18	11
or 16/4 per cubic yard; therefore			
1 cubic yard of concrete = ...	0	16	4
Mixing and wheeling to site, per cubic yard =....................................	0	2	6
Shuttering, per cubic yard = ...	0	1	0
Water pipes, &c., per cubic yard = ...	0	0	4
Total per cubic yard	£1	0	2

From the foregoing the following estimate can be formed :—

				£	s.	d.
Foundations:						
Soft rock cutting...	3,400 cubic yards	at	3/-	510	0	0
Hard rock cutting ...	1,980	,,	7/6	742	10	0
Masonry:						
Masonry (building)	18,000	,,	5/-	4,500	0	0
Stone	12,000	,,	5/6	3,300	0	0
Mortar ...	6,000	,,	24/-	7,200	0	0
Concrete...	2,340	,,	20/2	2,359	10	0
Watering	18,000	,,	-/2	150	0	0
Pointing:						
Inner face	2,200 square yards	at	5/6	605	0	0
Outer face	2,150	,,	2/-	215	0	0
Superintendence, time-keeping, &c., say 5 per cent. of total....................				979	2	0
Total cost				£20,561	2	0

Equal to £1 2*s.* 10*d.* per cubic yard of building.

The above requires, in addition, valve tower, discharge pipes, scour pipes, valves, railing, cleaning basin of reservoir, &c., &c., and is only given to indicate the cost per cubic yard with materials at about the above cost.

The Tausa Dam, Bombay, built 1886–92, cost for masonry only 14*s*. 8*d*. per cubic yard, but there were upwards of 407,407 cubic yards in the structure, which was built with hydraulic lime, the limestone being found near the site of the works, and labour was abundant and cheap.

The famous Furens Dam, built over 40 years ago, cost about 14*s*. per cubic yard, but such prices are exceedingly low, and depend largely on the essential material, cement—its cost on the site of the works influencing greatly the price per cubic yard.

The three principal items of cost in the foregoing estimate—viz., masonry building, stone, and mortar—come to 16*s*. 8*d*. per cubic yard.

APPENDIX II.

Form of Specification.

The forms of Specification and Schedule of Prices given in the following pages are subject to additions and alterations according to the customs prevailing, and the materials obtainable, in the district in which the dam may be constructed. There are customs, not to say prejudices, in various parts of the world which cannot be overlooked in arranging contracts, and what may be the general usage in England may not be satisfactory or applicable in other countries.

As an indication and outline the forms may be found useful, and, it is hoped, of assistance in the compilation of a specification that shall insure a satisfactory and honest piece of work being carried out—a guaranteed monument of stability and safety that may redound to the credit of the engineer and the contractor, whilst giving health and bounty to the district to be supplied with water.

It will be observed that no mention is made in the Specification of the gauge house and apparatus requisite for controlling the discharge, this not coming within the scope of the present treatise. Such information will be found in all works upon Hydraulic Engineering and Water Supply. Other additions may also be required,

such as filter tanks, &c. The main object here is to confine attention to the design and construction of the dam itself and such preliminary details as form part of the work of the engineer.

[*Title of Dam to be specified here.*]

SPECIFICATION TO BE OBSERVED IN THE CONSTRUCTION OF THE WORKS NECESSARY FOR THE SUPPLY OF WATER TO , &C., IN ACCORDANCE WITH THE DRAWINGS NUMBERED 1 TO INCLUSIVE.

General Description.—The contractor is to provide the whole of the labour, carriage, tools, implements, tackle, legs, cranes, staging, pumps, and all other things requisite for the construction of the dam, valve tower, outlets, &c., to the forms and dimensions and in the position shown on the drawings.

Clearing Site of Reservoir.—The contractor shall remove all walls and fences, root out all trees, hedges, and brushwood, and clear away all mounds, loose earth, and rubbish within the area to be occupied by the reservoir. The material so obtained, as far as not claimed by the proprietors or tenants of the land, shall belong to the contractor.

Excavation. Foundations.—The loose and weathered portion of the rock to be stripped off to the solid for the whole width of the wall at its base and cut into horizontal beds. On the completion of the foundations of the wall a trench is to be cut in the solid rock without blasting, as shown on the drawings, and of such a depth as to effectually cut out all false seams, springs, veins of soft material, clay, &c., and to such further depths at any part of the foundations as may be found necessary by the nature of the ground, or as may be ordered by the engineer or his assistant. All loose and unsound places that may be caused during the execution of the works shall be excavated, and the foundations kept dry and clear of all obstructions, whether

arising from springs or drains, &c. No extra allowance will be made on account of the depth of the stripping or trench until such depth exceeds feet below the surface shown on the sections. For depths exceeding feet the contractor will be paid according to the rates stated by him in the schedule for the various depths mentioned therein. The prices given by the contractor are to include the cost of close sheeting the trench if necessary, and keeping it free of water by means of such pumping engines and other appliances as may be necessary.

Before any concrete is put in the trench is to be inspected by the engineer or his assistant, to whom at least days' notice must be given; and great care must be taken to have the bottom of the trench thoroughly cleaned out, scraped, and watered before putting in the concrete, so that a perfect and water-tight junction may be made. This applies equally to the whole foundation of the dam. Notwithstanding this inspection, however, the responsibility of making the reservoir water-tight shall rest with the contractor.

Waste.—The excavated waste from the stripping and trench shall be removed and deposited at such a distance and place from the works as may be indicated by the engineer or his assistant.

Concrete.—The cement concrete used for filling in the trench in the foundations shall be composed of parts by measure of cement to parts by measure of sand and parts by measure of hard sharp stone, the sand and cement to be thoroughly well mixed before the water is added, the cement and sand to be worked into a mortar the consistency of which is such as will incorporate readily with the stone. The stone is to be perfectly free from sand or dirt and not larger than 2½ inches cube or smaller than 1½ inch cube, to be well wetted before being mixed with the cement mortar, and the whole aggregate to be well turned over to ensure perfect incorporation. The ingredients are to be mixed by machines of approved construction or by

shovels upon a specially close-jointed timber floor of ample area and conveniently near the site of the works.

In no case is the concrete to be tipped or shot into the foundations, but to be laid in carefully in horizontal layers of one foot in thickness, to be afterwards rammed with wooden or iron rams until a film of water appears upon its surface, but not to make it quake.

No concrete or mortar is to be worked up the second time after partial setting, nor to be applied to a dry surface.

Should the weather be dry immediately following the completion of any portion of the work, the concrete, when sufficiently set, shall be regularly drenched with water in order to prevent the cracking of the surface.

Any portion that is left for a few days is, before placing more concrete upon it, to have its surface well swept, picked, and cleaned, so that a perfectly water-tight joint may be made.

The contractor will be obliged to remove and replace all concrete which in the opinion of the engineer or his assistant has been injured by frost, &c., while the works are in progress or during the period of maintenance.

Sand.—The whole of the sand used in the works, where not otherwise specified, is to be clean and sharp, not over coarse, and to be well washed before use.

Cement mortar.—The cement mortar is to be composed of parts by measure of cement to parts by measure of sand, to be thoroughly well mixed before applying the water, and each quantity of mortar made is to be brought to the same consistency as that previously used, sufficient only being made for the immediate requirements, all mortar showing signs of setting to be rejected.

The ingredients are to be mixed by machines of approved construction as in the case of the concrete.

Cement.—The Portland cement shall be of the best quality and from manufacturers of the highest standing, approved of by the engineer; it shall be of such a fineness as to pass a sieve of 14,400 holes per square inch, leaving

a residue of not more than 10 per cent. Briquettes are to be made from the cement with not more than 20 per cent. of water by gauging, the same to stand after seven days' immersion in water 350 lbs. per square inch tensile strain, and after 28 days 500 lbs. per square inch, or an increase of not less than 25 per cent. between the two tests; the strain to be applied at the rate of 400 lbs. per minute. The cement must be on the ground at least one month before it is required, to allow time for testing. The engineer or his assistant shall take the requisite samples out of each delivery (for the purpose of making such tests as he may desire), and should any delivery fail to stand the specified tests it shall be at once removed by the contractor and replaced by him with cement of the proper quality.

The cement when received on the works is to be well and dryly stored in a shed with raised floor built for the purpose by the contractor, space being provided for cooling. The cement to be stored in heaps of not more than six sacks depth, and not less than a week before using to be spread out, on the floor provided, to one foot depth, being turned every alternate day.

Proper measuring vessels are to be provided and constantly used by the contractor, each cubic foot holding not less than 90 lbs. of cement; if, owing to the fineness of the cement, not more than 85 lbs. can be contained in the cubic foot gauge box, the box is to be increased in size so as to hold 90 lbs. when striked, it being understood that this is the required weight per cubic foot gauge for the whole of the work.

Cement testing machine, &c.—A cement testing machine of approved make, together with the moulds, water tanks for briquettes, and other requisites shall be provided by the contractor for the use of the engineer or his assistant, and be at their disposal at any time when required, the same to be kept in a lock-fast house and the key in the possession of the engineer. On the completion of the works the contractor shall resume possession of the machine.

Stone and quarry.—The stone used in the work is to be of the best hard and sound class found upon the site of the works, free from seams and cracks, and to be approved of by the engineer. No quarrying operations are to be carried on within or below the overflow level of the reservoir or within   yards from the down stream face of the dam.

Construction.—The dam is to be constructed of uncoursed rubble masonry throughout, anything approaching regular horizontal joints to be carefully avoided, pains being taken to preserve a good bond throughout the whole breadth of the work; the whole to be carried up as much as possible of an uniform height, and in no case is there to be a greater difference of the levels in any parts of the same building than   feet without the special permission of the engineer.

All the building stones used are to be placed on their natural bed, and none are to be of less size than $\frac{1}{2}$ cubic foot, all weak corners being knocked off before placing in position, every stone to be laid full in mortar, each one being selected so as to roughly fit the place it is laid in and driven home with a light mallet, all spaces between it and the adjacent stone to be filled flush with mortar, spalls or small stones to be inserted in the mortar between the joints, care to be taken that the mortar and stone do not dry before setting the corresponding course or that any dry work or hollow spaces occur in the work.

The face stones and those used for the valve tower and gallery are to be specially selected, and, where necessary, cut to their true centres from templates. Grouting will in no case be permitted.

The face joints on the up stream face to be left with a 2 inch depth for pointing with a specially prepared cement mortar, consisting of 1 of cement to 1 of a finely ground hard sand by measure, to be slightly stiff for use, and driven in tightly into the joints with wooden implements. The down stream face and valve tower joints to be clean

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trimmed and pointed with the same strength of mortar as used in the construction.

The valve tower and connection to the outlet gallery to be built with a cement mortar of the same mixture as that for the pointing of the up stream face.

Waste weir.—The waste weir is to be constructed to the dimensions and in the manner shown on the drawings, the paved apron to be built with specially selected stone set in a cement mortar of 1 of cement to 2 of sand by measure and evenly pointed on the surface so as to offer the least friction to the flow of the water.

Protection of works.—Every precaution is to be taken to protect the works from the weather; and any work that may be injured by frost or otherwise is to be made good by the contractor.

Cast iron pipes.—The pipes required are to be cast vertically in dry sand moulds and to be of uniform bore and thickness throughout, to be of the best grey metal remelted from the cupola, and to be perfectly free from flaws and defects of any kind.

All pipes and special castings in which any imperfections shall appear, or wherein any sand holes or air holes shall be found plugged up, or shall not agree with the terms of the specification, will be rejected, and must be broken up in the presence of the engineer or his assistant.

The pipes are to be carefully coated on the inside only with coalpitch and oil, according to Dr. R. A. Smith's patent process, the coating to be applied at a proper heat and in a proper manner before any rust sets in.

The exterior of the pipes must be cleaned of all tar, oil, or grease, and be well picked with a sharp implement on the outer surface to roughen it, each pipe before being set in position to be struck with a heavy hammer, and should there be by this test any false ring, or doubt as to its soundness, it must be rejected and broken up. When set in position and bolted up the pipes are to be tested to a pressure of 250 lbs. per square inch by an

approved machine. The pipes whilst this pressure is on them must be rapped with a hand hammer from end to end, so as to discover whether there are any sandy, porous, or blown places, any sign of leakage at the joints to be rectified before they are built in. The testing to be done by the contractor at his own expense and in the presence of the engineer or his assistant.

Bolts and nuts, &c.—The wrought iron in the bolts, nuts, &c. must be of the best make. The contractor is to state what class he proposes to use, which must bear a test of 24 tons to the square inch without breaking, and must be capable of being bent, whilst cold, to a right angle without fracture; it must also bear a tensile strain of 10 tons to the square inch without permanent set. Any of the wrought iron bearing traces of oxidation will not be used in the work.

Valves.—The sluice valve for the scour pipe and the valves in the valve tower, &c., must be made of the best gun metal and of approved pattern. They must also be tested to 250 lbs. per square inch, and any leakage or defect must be immediately rectified or the valve rejected, it being understood that the valves shall be watertight and work satisfactorily.

Building in of pipes.—Great care is to be exercised in the building in of the scour pipes and the connections of the discharge pipes from the inner to the outer part of the valve tower that a secure joint is made between the rubble masonry, &c., and the iron pipes.

General Conditions.

Omissions of details on plans, &c.—All the works, although parts of the same only may be marked on the plans and sections, are part of the contract, and included therein, as much as if such works had been particularly set forth and described in the specification also. Such of the works as may be mentioned in the specification only,

without being drawn on the plans or sections, are included in the contract as if they had been particularly drawn on the plans and sections also, and as there may be details not particularly mentioned in the specification, nor drawn in the plans and sections, the contract must be taken to include all such details as may have thus been omitted, it being clearly understood that the contractor is to execute all the works requisite for the perfect completion of each and every of the several parts according to the true intent and meaning of the specification.

Drawings.—Wherever the dimensions are marked on the plans and sections, or described in the specification, such dimensions are to be considered as correct, although not exactly corresponding with the measurements from the scales, which must be referred to only when the dimensions are not so marked or described. The drawings to larger scales, and those showing particular parts of the work, must be taken as more correct than those to smaller scales, or for more general purposes. The contractor must, without any extra charge, execute the several parts of the work in strict compliance with the working or detailed drawings that may from time to time be furnished by the engineer.

Custody of drawings.—The drawings referred to in the specification, and signed by the contractor, shall remain in the custody of the engineer during the progress of the works, the contractor being allowed access to them at all reasonable times, for the purpose of taking copies of the whole or any portion of them he may require.

Alterations and deviations. — The engineer may increase, diminish, or alter the work without vitiating the contract. The value of such increases or diminutions or alterations being ascertained from the rates and prices stated in the schedule annexed to the contract, and being added to or deducted from the contract sum as the case may be.

Extra work.—No extra work of any kind or description whatever will be paid for by   unless it has been

executed under a written order signed by the engineer or his assistant, and a weekly bill of all such work, or such parts thereof as may be executed, must be delivered by the contractor to the engineer or his assistant during the following week, and the non-delivery of such bill at the proper and stated time will be considered as an abandonment on the part of the contractor of any claim for the amount of such work, and as exonerating the   from all liability relating thereto. The value of all such extra work will be paid for according to the rates and prices stated in the schedule annexed to the contract.

Measurements.—All measurements must be the net dimensions of the work when finished, notwithstanding any custom that may prevail to the contrary. All metal used in the work must be weighed, and a note of the weight delivered to the engineer or his assistant previously to the work being fixed, the weighing being done in such a manner as will allow of the weight of any particular part of the work being ascertained.

Materials and workmanship.—The whole of the works, both as regards quality of materials and mode of execution, must be performed and completed in the most approved, workmanlike, and substantial manner, under the direction, and to the entire satisfaction, of the engineer.

Power to inspect materials.—The engineer or his assistant may at any time inspect the materials and manufacture of the various parts of the works, and if the contractor refuse to allow such inspection the work will be deemed insufficient and not in accordance with the terms of the specification.

Use of land.—The contractor shall not use the land forming the site of or connected with the works for any other purpose whatever than the proper carrying on of the works.

Temporary huts.—Should the contractor require to erect temporary huts for his workmen, or other temporary

buildings, the sites must be approved by the proprietors of the land and by the engineer or his assistant.

Trespassing.—The workmen are to be prohibited from trespassing on the neighbouring lands, from disturbing the sheep or cattle, and from killing, disturbing, or otherwise injuring the fish or game. The contractor is to dismiss at once, on the application of the engineer or his assistant, any workman or foreman so engaged, and to punish, so far as he has the power, all trespassers and poachers.

Neither the contractor nor any one in his employment will be allowed to keep a dog on the works, nor to fish in any of the streams.

Accidents.—The contractor must use all reasonable precautions to prevent accidents in the carrying out of the works; he shall provide proper storage for explosives, and careful and experienced men for handling them, and he must undertake liability for all accidents or damage that may occur in connection with the carrying out of the works, whether to his own workpeople, to the general public, or to property of any kind; and must free and relieve the   the engineer, or his assistant, from any claims that may be made against them in respect to such accidents or damage.

In case of dispute between him and any party claiming compensation, or if the claim is made directly against the   , the amount of such compensation shall, with the consent of the party claiming compensation, be fixed by the engineer, whose decision on that point shall be final, the amount to be deducted from any sum that may be due or may become due to the contractor.

The contractor must also use every precaution to guard against accidents or injury to the works by reason of floods, or by the action and pressure of water, or by frosts, slips, or leakage, and should any such damage take place from such or other causes he shall forthwith repair and make good the same at his own expense.

Removal of rubbish.—The contractor shall from time to time

remove all surplus and objectional materials, waste, or rubbish from the works, and from any land or premises where any portion of the work may be carried on.

Foreman or workmen.—The contractor shall employ at his own cost and charge a competent foreman or engineer, who is to be constantly on the work, to ensure efficient control and superintendence, and who shall be duly authorised to act and receive instructions from the engineer or his assistant, and any instructions given shall have equal validity as if given to the contractor himself. No person shall be employed or allowed to remain on the work or any part thereof who shall be objectionable to the engineer.

Contractor to attend to engineer's orders and directions.—The contractor shall attend to and execute without delay all orders and directions which may from time to time be given by the engineer or his assistant in connection with the contract, and if he refuse to comply with all such orders and directions, or become bankrupt, or insolvent, or does not proceed with all due diligence and expedition within twenty-four hours after a written notice requiring the same has been delivered to him or his foreman, the engineer may use, free of cost and charge for wear and tear, all or any of the contractor's men, tools, implements, and materials which may be on the work or in use at the time, and also employ other men, tools, implements, and materials to perform such works as he may require and direct, agreeably with the specification; and all the costs, charges, and expenses of the same shall be deducted from any amount that may be due to the contractor and retained by the   in re-imbursement of all such costs, charges, and expenses.

Notice to the contractor.—All notices to the contractor shall be given in writing, and the delivery of them to his foreman, or at any of the contractor's usual places of business or residence, shall be deemed sufficient service.

Imperfections or insufficient workmanship.—If at any time

during the progress of the works, or within twelve calendar months after the completion, any imperfections, leakage, or insufficient workmanship shall appear, the contractor shall forthwith make good the same at his own expense; the true intent and meaning of the specification being that the whole of the works shall be delivered up to the properly and completely finished and perfect in all their parts, and in conformity in every respect with the contract.

Watchman.—From sunset to sunrise, and when required, a watchman is to be kept on Sundays and all other times when the works are not in progress until they are completely finished.

Spirituous liquors.—The contractor shall not sell or allow to be sold or brought within the limits of his work any spirituous liquors, and will in every way discountenance their use by persons in his employ.

Inspector of works or clerk of works.—The engineer shall appoint a clerk of works or inspector to take charge of and supervise the various sections of the work during its construction, and the said assistant of the engineer shall have it in his power to dismiss any foreman or workman who may be unskilled or inefficient, or who may refuse or neglect to attend to their orders or instructions, or to those of the engineer given through him.

Office for assistant.—The contractor shall provide an office for the clerk of works or inspector appointed, the same to be provided with stove, desk with drawer, lock and key, the floor to be boarded, and windows and doors provided where necessary with necessary fastenings.

Maintenance of works.—The contractor, notwithstanding the use of the said works for the purpose of water supply and storage, shall be responsible for, and shall maintain and uphold in a sound and perfectly water-tight condition, every part of the works for a period of twelve months from the date of the engineer's certificate of completion. In the event of the contractor failing to make any

necessary repairs when called upon to do so the same may be done by the engineer or his servants and the cost thereof retained from any sum that may be due or become due to the contractor.

Period of completion.—The entire work shall be warranted by the contractor and completed within from the date of the written order to proceed with the work, under a forfeiture of per week, to be paid to and retained by , by way of liquidated and ascertained damages, and not by way of penalty, for each week and every week the work shall remain unfinished after the expiration of the period above mentioned.

Completion of works.—The works shall not be deemed finished or complete until they shall have been certified to be so in writing by the engineer.

Power to delay works.—The engineer may delay the progress of the works without vitiating the contract, and grant such extension of the time for the completion of the contract as he may think proper and sufficient in consequence of such delay, and the contractor shall not make any claim for compensation or damage in relation thereto.

Disputes.—If at any time during the progress or after the completion of the works any disputes or differences shall arise as to the manner of executing the works, or as to the quality of the materials employed, or as to any matter of charge or account between the and the contractor, or as to any other matter or thing connected with the contract, they shall be referred to and finally settled by as sole arbiter, whose decision shall be final and binding on both parties.

Payments.—Payments shall be made upon the recommendation of the engineer, the first of such payments whenever he may consider that per cent. of the work contracted for has been executed, and the subsequent payments from time to time when it shall appear to him that a similar proportion of the work contracted for has been delivered and executed since the preceding payment. All such

payments will be at the rate of 80 per cent. of the works so considered to have been executed, whether contract or extra works. One half of the balance due will be paid on the completion of the works, and the remainder at the expiration of twelve calendar months after their completion, under deduction of all claims against the contractor.

Contract.—Before commencing the works the contractor shall enter into a formal contract with the for the execution of the work, providing such security as may be satisfactory to them, which contract shall contain all the usual provisions and stipulations, and he shall pay one half of the cost of preparing the same.

Tenders.—Tenders on the printed form with schedule must be filled up and addressed to the , and endorsed , and are to be delivered at on or before o'clock in the morning of inst. The amount of the tender is to be such as to cover all contingencies and omissions in the drawings and specification, the prices in the schedule being for the purposes of computing the value of extra work.

The do not bind themselves to accept the lowest or any tender.

Date (Signed)

Schedule of Prices to Accompany Tender.

Excavator's Work.

Excavating and removing from site of works when the depth does not exceed 6 feet.........	at	per cubic	yard.
Ditto ditto 12 ,, ...	,,	,,	,,
Ditto ditto 18 ,, ...	,,	,,	,,
Ditto ditto 24 ,, ...	,,	,,	,,
Ditto ditto 30 ,, ...	,,	,,	,,
Ditto ditto 36 ,, ...	,,	,,	,,
Ditto ditto 40 ,, ...	,,	,,	,,
Clearing ground and removing rubbish within interior of reservoir	,,	,,	,,

Note.—All the above prices are also to include all matters and things referred to in the specification as to maintaining the excavation open and dealing with water, &c.

Mason's Work.

Concrete	at	per cubic	yard.
Stone...............................	,,	,,	foot.
Ditto in mortar....................	,,	,,	,,
Cement ,, ...	,,	,,	yard.
Cut and tooled stone for valve tower, arch, &c.	,,	,,	foot.
Ditto ditto ditto in mortar...	,,	,,	,,

Ironwork, &c.

Wrought iron rolled beams......	at	per cwt.
Ditto ┬ irons and └ irons	,,	,,
Ditto bolts and nuts...............	,,	per lb.
Cast iron pipes with special flanges	,,	per cwt.
Ditto ditto ordinary flanges	,,	,,
Bronze valves	,,	per lb.
Railing	,,	per lineal yard.
Painting	,,	per superfic. yard.

Labour only.

Excavator	at	per hour.
Labourer to ditto	,,	,,
Mason	,,	,,
Labourer to ditto	,,	,,
Horse, cart, and man	,,	,,
Extra horse	,,	,,
Fitter	,,	,,
Rivetter	,,	,,

Signature

Address

Date

Form of Tender.

Proposal of   *for Building Masonry Dam, &c.*

Date

Messrs. The

Gentlemen,—   offer to execute the whole of the works, to furnish all the materials, labour, plant, complete and maintain the work in accordance with the plans, sections, and specification, and with such direction as may from time to time be received from the engineer, for the sum of sterling.

The above amount includes all materials, workmanship, labour, scaffolding, tools, and machinery, and every expense necessary for the completion of the whole work.

In the schedule   have given the prices for the various classes of work upon which all extra work will be calculated, and   undertake to complete the whole contract within   months from the date of receiving order to proceed.

Gentlemen,

Your obedient servant,

(Signed)

Amount of tender   Address

References

Address

APPENDIX III.

Purity of Water.

An important part of the investigation required previously to the erection of a dam is the question of the purity of the water which is to be retained by the dam from the drainage area, and any one in search of a pure supply of water will be glad of a few simple tests and instructions which may enable him, without the necessity of an expert's assistance in the preliminary work, to ascertain with a certain degree of probability whether the water which it is proposed to utilize is of sufficient purity to warrant its recommendation for domestic supply. Any water that it might be proposed to impound for the supply of a large town would, undoubtedly, require to be subjected to a searching examination before expense was incurred for the works necessary for a constant supply, and the following extract* is only given here as a useful guide to the prospector for water :—

* From the "American Engineering and Mining Journal."

TEST FOR PURITY OF DRINKING WATER.

By FRANCIS WYATT, Ph.D.

When chemists apply the word "pure" to water they of course only do so in a comparative sense, because perfectly pure water does not exist in nature. Even in its primary form of rain it contains some traces of ammonia and nitrates, derived from the atmosphere, and it always becomes more or less charged with earthy and saline matters before it reaches the streams. The rivers are charged with impurity and refuse from towns on their banks, and the water becomes gradually more dangerous; and, although it is somewhat purified by oxidation and the absorbent action of vegetation, it requires the most conscientious and watchful care in the reservoirs of great communities.

All upland surface waters vary in quality in accordance with the nature of their surrounding conditions, but they are characterised as "pure" and accepted as satisfying all necessary conditions for drinking and household purposes when they have no disagreeable taste or smell, when they are only of medium hardness and are free from excess of salt, and when they have no poisonous minerals and only a minimum of organic contamination.

In order to ascertain whether or not a given source of water really fulfils the needed requirements it must be subjected to the closest scientific scrutiny, for little reliance can be placed upon the public taste. Nothing less than the determination, within reasonable limits of accuracy, of the amount of matter in the water, and of the probable origin of the impurities, is of much public value, and this determination is only

rendered possible by accurate chemical and biological examinations. It is no exaggeration to say that, from a sanitary standpoint, the difficulties in the way of assigning proper importance to the various ingredients discovered in an analysis are well-nigh insurmountable. In fact, so great are they that careful chemists invariably make their reports and conclusions only after comparing their own conditions and results with the results recorded for similar conditions over a long period of years by established authorities.

The main causes of perplexity and doubt are not the inorganic salts, which all drinking waters contain in more or less abundance, but those complex and enigmatical bodies which have come to be classified under the heads of organized and unorganized organic matter. The real difficulty in the sanitary analysis of a water is to show—first, how far it is contaminated with bacteria or micro-organisms; and, second, to what extent it is capable of affording nutrition to such organisms in the form of readily decomposable feeding material.

There being no prescribed rule of general applicability by which the interpretation of a purely chemical analysis of water can be made by the ordinary reader, the mere publication of certain analytical results, even by the best authorities, are practically without significance, since they are commonly unaccompanied by any detailed and intelligible or popular explanations.

The following figures approximate to what I regard, after a wide experience, as the typical salient points in a perfectly safe surface water; 100,000 parts of a potable water may contain: total inorganic solid residue, 5 up to 50 parts; chlorine, 0·10 up to 1 part; phosphates, none; nitrites, none; free ammonia, 0·005 parts; albuminoid ammonia, 0·015 parts; oxygen consumed, 0·250 parts; poisonous minerals, none. It is possible that such an analysis as this would not call forth very extensive comment, but in cases which show any notable

increase in any or all of my figures, and where some turbidity, or colour, or taste, or smell, are also noted, the report of the analyst should be supplemented by some remarks upon, (1) the behaviour on ignition of the total solid residue, (2) the quantity of the free and albuminoid ammonia and their proportionate relation to each other, (3) the quantity of oxygen absorbed by a normal sample of the water from permanganate of potash, and the time required for such absorption, (4) the amount of nitrous acid or nitrites, (5) the quantity of chlorine. These annotations should be further accompanied by explanatory foot-notes, stating in a general way, for the benefit of the uninitiated, that when residual solids turn very black on ignition, and emit an odour resembling burnt hair, they point to the probable presence of animal matter. That when the quantity of free ammonia is very high, and especially when it is accompanied either by nitrous or phosphoric acid, or by both, the indications are strongly in favour of recent sewage contamination; that when, in addition to much free ammonia, the albuminoid ammonia exceeds the figures 0·015, it is to be regarded as a measure of the potential putrescible animal matter which still exists in the water, and which will afford food for innumerable ferments of all species. That, when the quantity of "oxygen absorbed," under certain conditions (by Forschammer's test), is more than 0·250, it is to be regarded as entirely confirmatory of the other data, as is the amount of chlorine when, in waters far from the sea, or from salt-bearing strata, it exceeds a maximum of two parts per 100,000.

Such information as this, modified to suit varying circumstances, would be of material assistance, even though it be based upon purely chemical tests. It might even become a generally applicable rule, and could be regarded as entirely conclusive if the figures obtained, and considered as a whole, were sufficiently abnormal to be startling.

Such cases, however, seldom occur in actual practice, the

numbers rarely exhibit any positive regularity, and usually only one or two of them are sufficiently high to excite suspicion. Here, therefore, the rule would no longer apply, and here commences the perplexity, which calls for additional evidence through the medium of the microscope. To again put it more plainly, the vitality of the micro-organisms present in the water must be made the gauge of its potential organic impurity in all cases of serious doubt.

During the past few years there has been immense progress in biological science, but it is not yet sufficiently great to enable us to say with authority, off hand, whether the organisms found in a water supply are disease-producing or innocuous. It does enable us, however, to determine the extent of their vitality and their approximate numbers, and from this we may deduce the value of the water as a nutrient medium for septic or other dangerous microbes that might gain access to it. The method most commonly used for the bacteriological examination of water consists in mixing a measured quantity of it (1 c.c.) in a test tube, with sterilized nutrient gelatin, and pouring the mixture upon a sterilized glass plate. After the gelatin has solidified the glass plate is placed in a damp chamber and kept at a uniform temperature of about 70° to 80° Fahr. for five or six days. Colonies of microbes have by this time made their appearance, and may be counted with the microscope by the aid of Wolffhugel's apparatus.

There can be no doubt of the excellence of this method, but in my own practice I have found it too tedious for commercial work, and have replaced it, after many experiments, by one which is more simple and expeditious, and gives equally satisfactory information. As culture media I use neutral, slightly acid, and slightly alkaline decoctions of malt extract sterilized by boiling in Pasteur flasks. These flasks are always kept on hand ready for immediate use, and the sterilization having destroyed all forms of life, and the trace of outside germs being absolutely prevented, the liquids preserve

themselves indefinitely without losing their brilliancy or undergoing the slightest change. When a water is submitted for analysis the first step is to shake it up well, to insure perfect homogeneity. When this has been done 1 c.c. of it is introduced into each of the three flasks by means of a sterilized pipette. The flasks are then kept side by side at a uniform temperature of 80° Fahr. for 48 hours, and the behaviour of each flask is very carefully watched, and a note is made from time to time of the fermentative activity of each. The operation is always conducted on exactly the same lines, and yields data which, when compared with that resulting from the chemical tests, is most useful and reliable.

For example, if a water which has yielded a marked excess of "albuminoid ammonia" in the chemical tests quickly clouds up and develops very active fermentation in the flasks, we have immediate and undoubted proof of the existence of large numbers and various species of bacteria, and since their activity has been developed in such widely differing nutritive media it is safe to regard them as probably containing many forms of a highly objectionable kind, and to denounce the water as impure and unfit for drinking purposes.

If it were argued against this condemnation that nearly all surface waters are more or less contaminated with vegetable matter, and that this matter is always accompanied by infusorial and other lower forms of vegetable life which grow in nutrient solutions, and which are nevertheless assumed to be harmless, it may be answered that this is a question for the pathologist.

The province of the chemist is to determine the condition of a water, and what I would emphasise is that the presence of very active bacteria in large quantities growing in neutral, acid, and alkaline media, under the circumstances named,

would, to my mind, invariably indicate sewage or animal contamination, and would constitute a danger signal of the highest significance. There are circumstances which, in certain cases, make it extremely difficult, if not impossible, to obtain complete scientific examinations of a water supply, but I do not consider that this need necessarily preclude the adoption of rational precautionary measures. We owe the adoption of such measures as we may command, not only to ourselves, but to those about us, and the duty may be discharged by means of a few simple tests which are very easily performed.

The following tests require no apparatus that is not found in every household, and I believe they are sufficient to determine whether any given water of unknown quality is safe for drinking purposes :—

1. Pour a glass of the water into a decanter, cork it, and shake it up violently for a minute or two. If it develops any bad smell after the operation the water may be suspected of sewage or other animal contamination.

2. Add to a small glassful of the water two or three drops of diluted sulphuric acid and stir, then pour in about two drops of a weak solution of permanganate of potassium, or sufficient to colour it a faint rose. Cover the glass with a saucer, and leave it standing for ten minutes, when, if the rose colour has entirely disappeared, the water is probably unwholesome, and requires to be investigated.

3. Take a very clean, dry glass, and put into it a few drops of a solution of nitrate of silver, and then pour in a couple of ounces of the water. If it becomes milky, add to it a few drops of diluted nitric acid. If the milkiness does not now nearly all clear away the water will be proved to contain much chlorine, and, unless it be taken from some source near the coast or near to salt springs, is probably contaminated with sewage.

4. Take two white eight-ounce bottles with well fitting stoppers, and wash them thoroughly clean. Nearly fill one of them with the natural water, and the other with the water after boiling it for thirty minutes. Now put into each bottle a teaspoonful of pure white granulated sugar. Shake them until the sugar dissolves, and then place them side by side at a temperature of about 80° Fahr., and let them stand for three days. If the unboiled water rapidly clouds up, and shows a marked fermentation, emitting an odour faintly recalling rancid butter, it probably contains phosphates, and may be suspected of contamination with sewage. If the boiled water shows any signs of decomposition the suspicion of serious contamination will be confirmed.

5. Pour a small quantity of the water into a white saucer, and carefully add to it one drop of sulphuret of ammonia. If a dark colour is formed, which immediately disappears on the addition of one or two drops of pure hydrochloric acid, iron salts are present. If the dark colour does not disappear the water contains other and probably poisonous metals, and should at once be rejected.

If any or all of the first four of these rough tests be doubtful or unfavourable in their results they will render service of incalculable value, if only by pointing to the necessity for purifying the water before it can be drunk with safety.

How this purification should be performed is a matter upon which there are numerous suggestions and much difference of opinion; the best and most efficient manner of doing it in the household is by boiling it for thirty minutes. Dr. Miguel, of Paris, has dispelled all doubt upon this subject by publishing the following figures:—Bacteria in each c.c. of water, at 60° Fahr., 460,800; 122° Fahr., for ten minutes, 600; 140° Fahr., for ten minutes, 90; 158° Fahr., for ten minutes, 89; 176° Fahr., for ten minutes, 63; 195° Fahr., for ten minutes, 27; 212° Fahr., for ten minutes,

none. This evidence is too striking to require any comment, and I will merely say in conclusion that if, after it is boiled, the water be first cooled, and then passed through an ordinary charcoal or other approved filter, its flat and uninviting taste will be immediately removed.

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